IMPROVING PUMPING SYSTEM PERFORMANCE

A SOURCEBOOK FOR INDUSTRY

Quick Start Guide

This Sourcebook is designed to provide pump system users with a reference outlining opportunities to improve system performance. It is not intended to be a comprehensive technical text on improving pumping systems, but rather a document that makes users aware of potential performance improvements, provides some practical guidelines, and details where the user can find more help. The Sourcebook is divided into three main sections listed below.

Section 1 Introduction to Pumping System

For users unfamiliar with the basics of pumping systems, a brief discussion of the terms, relationships, and important system design considerations is provided. This *Pumping System Basics* section describes the key factors involved in pump selection and system design and provides an overview of different types of pumps and the applications for which they are generally used. Users already familiar with pumping system operation may want to skip this section. The key terms and parameters used in selecting pumps, designing systems, and controlling fluid flow are discussed.

Section 2 Performance Improvement Opportunity Roadmap

This section describes the key components of a pumping system and the opportunities for performance improvements. Also provided is a figurative system diagram identifying pumping system components and performance improvement opportunities. A set of Fact Sheets describing these opportunities in greater detail follows the diagram.

Click here to link directly to the FACT SHEETS

Section 3 Where to Find Help

Section 3 provides a directory of associations and other organizations involved in the pump marketplace, along with a listing of the resources, tools, software, videos, and workshops.

Appendices

The Sourcebook includes three appendices. Appendix A is a glossary defining terms used in the pumping system industry. Appendix B presents an overview of the pumping system marketplace. Appendix C provides a screening tool that can help identify and prioritize energy improvement projects in pumping systems.

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SECTION 1: INTRODUCTION TO PUMPING SYSTEMS

Table of Contents

INTRODUCTION TO PUMPING SYSTEMS

Pumps are widely used in industry to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. In fact, most manufacturing plants, commercial buildings, and municipalities rely on pumping systems for their daily operation. In the manufacturing sector, pumps represent 27 percent of the electricity used by motors. In the commercial sector, pumps are primarily used in heating, ventilation, and air conditioning (HVAC) systems to provide water for heat transfer. Municipalities use pumps for water and wastewater removal and treatment and for land drainage. Since they serve such diverse needs, pump sizes range from fractions of a horsepower to several thousand horsepower.

In addition to an extensive range of pump sizes, there are also several different types of pumps. Pumps are classified by the way they add energy to a fluid: **positive displacement pumps*** squeeze the fluid directly, while **centrifugal pumps** speed up the fluid and convert this kinetic energy to pressure. Even within these classifications there are many different sub-categories of pumps. Positive displacement pumps include piston pumps, screw pumps, sliding vane, and rotary lobe pumps, while centrifugal pumps include axial (propeller) pumps, mixed flow, and radial pumps. Many factors determine which type of pump is suitable for an application and often several different types will meet the service requirements of an application.

Pump reliability is often critical. In cooling systems, pump failure can result in equipment overheating and catastrophic damage. In lubrication systems, inadequate pump performance can destroy equipment. In many petrochemical and power plants, pump downtime can cause a substantial loss in productivity.

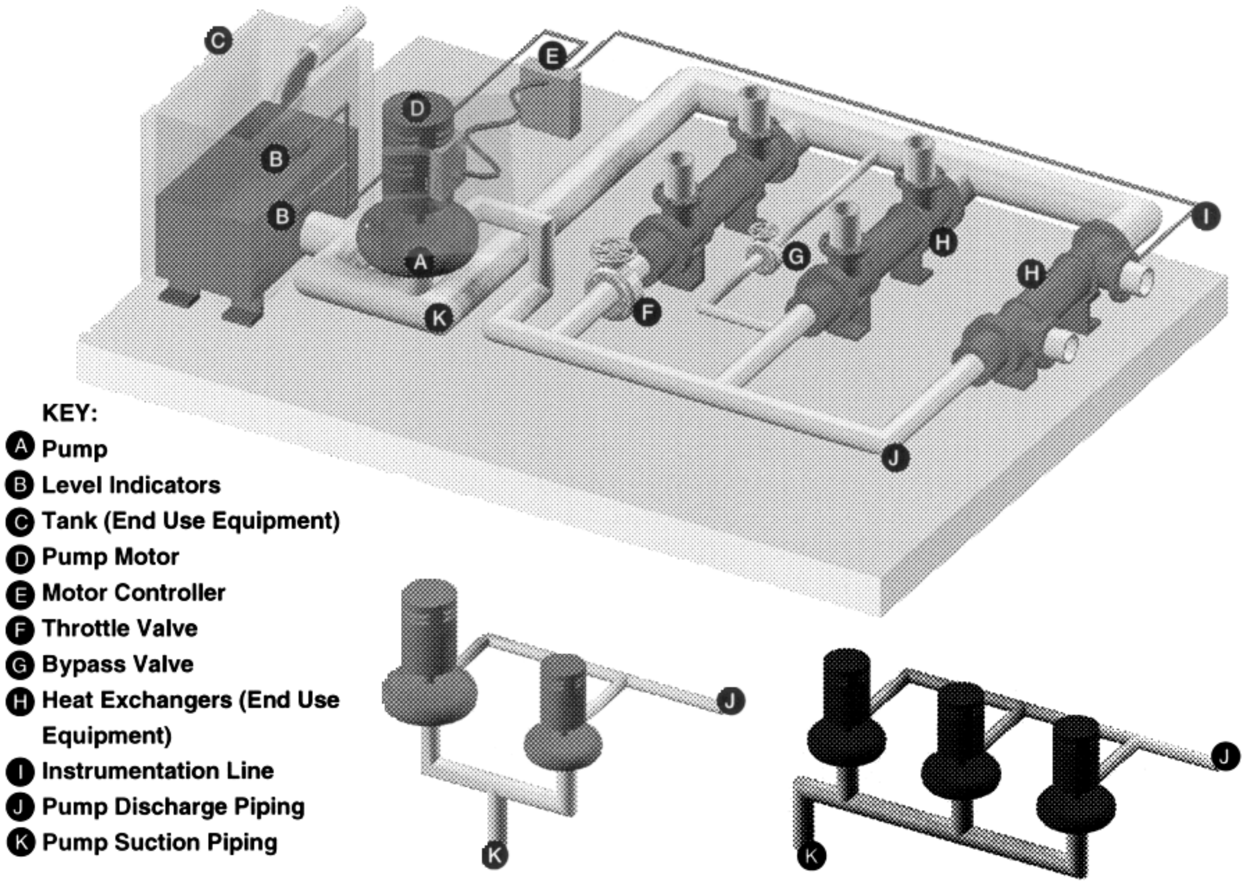
The importance of pumps to the daily operation of many facilities promotes the practice of conservatively sizing pumps to ensure that the needs of the system will be met under all conditions. Intent on ensuring that pumps are large enough to meet system needs, engineers often overlook the costs of oversizing pumps and err on the side of safety by adding more pump capacity. Unfortunately, this practice results in higher-than-necessary system operating and maintenance costs. In addition to inefficient operation, oversized pumps typically require more frequent maintenance than properly sized pumps. Excess flow energy increases the wear and tear on system components, resulting in valve damage, piping stress, and noisy system operation.

Pumping System Components

Typical pumping systems contain five basic components: pumps, prime movers, piping, valves, and end-use equipment (e.g. heat exchangers, tanks, and hydraulic equipment). A typical pumping system and its components are illustrated in the following diagram.

***Terms in bold blue type are defined in the Glossary, Appendix A**

Diagram A. Typical Pumping System and its Components



Alternative Pump Configuration: Large Pump with a Pony Pump

Alternative Pump Configuration: Multiple Pumps

Pumps

Although pumps are available in a wide range of types, sizes, and materials, they can be broadly classified into two categories -- positive displacement and centrifugal -- which relate to the manner in which the pumps add energy to the working fluid. Positive displacement pumps pressurize fluid with a collapsing volume action, essentially squeezing an amount of fluid equal to the displacement volume of the system with each piston stroke or shaft rotation. Centrifugal pumps work by adding kinetic energy to a fluid using a spinning **impeller.** As the fluid slows in the diffuser section of the pump, the **kinetic energy** of the fluid is converted into a pressure increase.

Although many applications can be served by both positive displacement and centrifugal pumps, centrifugal pumps are more common due to their simple and safe operation, low maintenance requirements, and characteristically long operating lives. Centrifugal pumps typically suffer less wear and require fewer part replacements than positive displacement pumps. Although the **packing** and **mechanical seals** must be replaced periodically, these tasks usually only require minor downtime. Centrifugal pumps can also operate over a broad range of conditions and have a low risk of catastrophic damage due to improper valve positioning.

Centrifugal pumps have a variable flow/pressure relationship. A centrifugal pump acting against a high system pressure generates less flow than it does when acting against a low system pressure. A centrifugal pump's flow/pressure relationship is described by a **performance curve** which plots the flow rate at various pressures. Understanding this relationship is essential to properly sizing a pump and designing a system that performs efficiently. For more information, see the Fact Sheet titled *Centrifugal Pump Performance Curves*.

In contrast, positive displacement pumps have a fixed displacement volume. Consequently, they generate flow rates directly proportional to their speed. The pressures they generate are determined by the systems' resistance to this flow. Positive displacement pumps have operating advantages which makes them more practical for certain applications. Positive displacement pumps are typically more appropriate for situations in which:

- The working fluid is highly viscous;
- The system requires high pressure, low flow pump performance;
- The pump must be self-priming;
- The working fluid must not experience high shear forces;
- The flow must be metered or precisely controlled; and
- Pump efficiency is highly valued.

To their disadvantage, positive displacement pumps typically require more system safeguards, such as relief valves. A positive displacement pump can potentially overpressurize system piping and components. For example, if all the valves downstream of a pump are closed--a condition known as deadheading--system pressure will build until a relief valve lifts, a pipe or fitting ruptures, or the pump motor stalls. Although relief valves are installed to protect against such damage, relying on these devices adds an element of risk. In addition, relief valves often relieve pressure by venting system fluid, which may be a problem for systems with harmful or dangerous system fluids. For more information on this type of pump, see the Fact Sheet titled *Positive Displacement Pump Applications*.

Prime Movers

Most pumps are driven by electric motors. Although some pumps are driven by direct current (dc) motors, the low cost and high reliability of alternating current (ac) motors make them the most common type of pump prime mover. In recent years, largely due to efforts by the Department of Energy, the efficiencies of many types of ac motors have improved. A section of the national Energy Policy Act (EPAct) setting minimum efficiency standards for most common types of industrial motors went into effect in October 1997. The EPAct should provide industrial end-users with increased selection and availability of energy efficient motors. In high run time applications, improved motor efficiencies can significantly reduce operating costs. However, often, a more important aspect to minimizing operating costs is a "systems approach" that uses proper component sizing and effective maintenance practices to avoid unnecessary energy consumption.

A sub-component of a pump motor is the motor controller. The motor controller is the switchgear that receives signals from low-power circuits, such as an on-off switch, and connects or disconnects the high-power circuits to the primary power supply from the motor. In direct current (dc) motors, the motor controller also contains a sequence of switches that gradually builds up the motor current during startups.

In special applications, such as emergency lubricating oil pumps for large machinery, some pumps are driven by an air system or directly from the shaft of the machine. In the event of a power failure, these pumps still can supply oil to the bearings long enough for the machine to coast to a stop. For this same reason, many fire service pumps are diesel engine driven to allow them to operate during a power outage.

Piping

Piping is used to contain the fluid and carry it from the pump to the point of use. The critical aspects of piping are its dimensions, material type, and cost. Since all three aspects are interrelated, pipe sizing is an iterative process. The flow resistance of a pipe decreases as it gets larger; however, larger pipe is heavier, takes up more floor space, and costs more than smaller pipe. Similarly, in systems that operate at high pressures (for example, hydraulic systems), small diameter pipes can have thinner walls than large diameter pipes and are easier to route and install; however, small diameter pipes restrict flow, which can be especially problematic in systems with surging flow characteristics.

Valves.

The flow in a pumping system is controlled by valves. Some valves have distinct positions either shut or open, while others can be used to throttle flow. There are many different types of valves and selecting the correct valve for an application depends on a number of factors: ease-of-maintenance, reliability, leakage tendencies, cost, and the frequency with which the valve will be open and shut.

In terms of application, valves can be used to isolate equipment or regulate flow. Isolation valves are designed to seal off a part of a system for operating purposes or maintenance. Flow-regulating valves restrict flow to either directly control flow through a system branch (throttle valve) or to bypass flow around it (bypass valve). A throttle valve controls flow by increasing or decreasing the flow resistance across it. In contrast, a bypass valve allows flow to go around a system component by increasing or decreasing the flow resistance in a bypass line. A check valve allows fluid to move in only one direction, thus protecting equipment from being pressurized from the wrong direction and helping to keep flow moving in the right direction. Check valves are used at the discharge of almost all pumps to prevent flow reversal when the pump is stopped.

End-use Equipment (Heat Exchangers, Tanks, and Hydraulic Equipment)

Since the essential purpose of a pumping system is to provide cooling, to supply or drain a tank or reservoir, or to provide hydraulic power to a machine, the nature of the end-use equipment is a key design consideration for determining how the piping and valves should be configured. There are many different types of end-use equipment; the fluid pressurization needs and pressure drops across this equipment varies widely. For heat exchangers, flow is the critical performance characteristic, while for hydraulic machinery, pressure is the key system need. Pumps and pumping system components must be sized and configured according to the needs of the end-use processes.

Pumping System Principles

Design Practices

Fluid system designs are usually developed to support the needs of other systems. For example, in cooling system applications, the heat transfer requirements determine how many heat exchangers are needed, how large each heat exchanger should be, and how much flow is required. Pump capabilities are then calculated based on the system layout, equipment characteristics, and pipe sizes. In other applications, such as municipal wastewater removal, pump capabilities are determined by the amount of water that must be moved and the height and pressure to which it must be pumped. Again, the piping and pumps are sized and configured according to the flow rate and pressure requirements of the system or service.

Upon identifying the service needs of a pumping system, the pump/motor combination, pipe sizes, layout, and valve requirements must be engineered. Selecting the type of pump and its speed and power characteristics requires an understanding of its operating principles.

The most challenging aspect of the design process is cost-effectively matching pipe size and pump and motor characteristics to the needs of the system. This process is often complicated by wide variations in flow and pressure requirements. Ensuring that system needs are met during worst case conditions can lead to specifying equipment that is oversized for normal operation. Unfortunately, specifying larger than necessary pipes and pumps increases material, installation, and operating costs.

Fluid Energy

For practical pump applications, the energy of a fluid is commonly measured in terms of **head**. Head is usually expressed in feet or meters, which refers to the height of a column of system fluid that has an equivalent amount of potential energy. This term is convenient because it incorporates density and pressure, which allows a pump to be evaluated over a range of system fluids. For example, at a given flow rate, a pump will generate two different discharge pressures for two different density fluids; however, the corresponding head for these two conditions is the same.

The total head of a system fluid consists of three terms or measurements: static pressure (gauge pressure), height (or potential energy), and **velocity head** (or kinetic energy). Static pressure, as the name indicates, is the pressure of the fluid in the system. It is the quantity measured by conventional pressure gauges. The height of the fluid level has a substantial impact on the static pressure in a system, but is itself a distinct measurement of fluid energy. For example, a pressure gauge on a vented tank will read atmospheric pressure. If this tank is located 50 feet above the pump, however, a pump would have to generate at least 50 feet of static pressure (for tap water, the gauge would have to read 21.7 psi) to push water into the tank.

Velocity head (also known as dynamic head) is a measure of a fluid's kinetic energy. In most systems, the velocity head is small compared to the static head. For example, the flow velocity in cooling systems does not typically exceed 15 feet per second, which is roughly equivalent to 3.5 feet of head (if the system fluid is water, this velocity head translates to about 1.5 psig). The velocity head of a fluid must be considered when siting pressure gauges during the design phase of a system, especially when the system has varying pipe sizes. A pressure gauge downstream of a pipe reduction will read lower than one upstream of the reduction, although the distance may only be a few inches.

Fluid Properties

In addition to the type of system being serviced, pump requirements are greatly influenced by fluid characteristics, such as **viscosity**, particulate content, and **vapor pressure**. Viscosity is a property that measures the shear resistance of a fluid. A highly viscous liquid consumes more energy during flow because its shear resistance creates heat. Some fluids, such as cold lubricating oil (at less than 60°F), are sufficiently viscous that centrifugal pumps cannot effectively move them. As a result, the range of fluid viscosities over the operating temperatures of a system is a key system design factor. A pump/motor combination that is appropriately sized for 80°F oil may be undersized for operation at a 60°F system temperature.

The quantities and properties of particulates in a system fluid also affect pump design and selection. Some pumps are intolerant of debris. Some multistage centrifugal pumps, for example, suffer severe performance degradation if the seals between stages become eroded. Other pumps are designed for use with high-particulate-content fluids. Due to the nature of their operation, centrifugal pumps are often used to move fluids with high particulate contents such as coal slurries.

The difference between the vapor pressure of a fluid and system pressure is a another fundamental factor in pump design and selection. The acceleration of a fluid to high velocities--

a characteristic of centrifugal pumps--creates a drop in static pressure. This drop can lower fluid pressure to the fluid's vapor pressure or below it. At this point, the fluid "boils," changing from a liquid to a vapor. Known as **cavitation**, this effect can severely impact pump performance. As the fluid changes phase during cavitation, tiny bubbles form. Since vapor takes up considerably more volume than fluid, these bubbles decrease flow through the pump. The damaging aspect of cavitation occurs when these vapor bubbles return to liquid phase in a violent collapse. During this collapse, high velocity water jets impinge onto surrounding surfaces. The force of this impingement often exceeds the mechanical strength of the impacted surface which leads to material loss. Over time, cavitation can create severe erosion problems in pumps, valves, and piping.

Another problem that causes similar damage is suction and discharge **recirculation**. Suction recirculation is the formation of damaging flow patterns that result in cavitation-like damage in the suction region of an impeller. Similarly, discharge recirculation is the formation of damaging flow patterns in the outer region of an impeller. These recirculation effects usually result from operating a pump at too low of a flow rate. To avoid this type of damage, many pumps are listed with a minimum flow rating.

System Types

Like pumps, pumping system characteristics and needs range widely but can be classified in general as closed-loop or open-loop systems. A closed-loop system recirculates fluid around a path with common beginning and end points. An open-loop system has an input and an output, as fluid is transferred from one point to another. Pumps that serve closed loop systems, such as a cooling water system, do not typically contend with static head loads (unless there are vented tanks at different elevations). In closed-loop systems the frictional losses of system piping and equipment are the dominant pump load.

In contrast, open-loop systems often require pumps to overcome static head requirements due to elevation and tank pressurization needs. An example of an open system is a mine dewatering system, that uses pumps to move water from the bottom of a mine up to the surface. In this case, static head is the dominant pump load.

Principles of Flow Control

Flow control is essential to system performance. Sufficient flow ensures that equipment is properly cooled and that tanks are drained or filled quickly enough. The need to generate sufficient pressure and flow to satisfy system requirements creates a tendency to oversize pumps and the motors that run them. Since systems are designed with flow control devices to regulate temperature and protect equipment from overpressurization, the tendency to oversize system pumps often burdens these flow control devices with high energy dissipation loads.

There are four primary methods for controlling flow through a system or its branches: throttle valves, bypass valves, pump speed control, and multiple pump arrangements. The most appropriate flow control method depends on system size and layout, fluid properties, and system sensitivity to flow rate changes.

A throttle valve chokes fluid flow such that less fluid can move through the valve, creating a pressure drop across it. Throttle valves are more efficient than bypass valves because, as they are shut, they maintain upstream pressure that can help push fluid through parallel branches of the system.

Bypass lines allow fluid to flow around a system component. A major drawback of bypass valves is their detrimental impact on system efficiency. The power used to pump the bypassed fluid is wasted.

Pump speed control includes both mechanical and electrical methods of matching the speed of the pump to the flow/pressure demands of the system. **Adjustable speed drives**, multi-speed pumps, and multiple pump configurations are usually the most efficient flow control options, especially in systems that are dominated by friction head, because the amount of fluid energy added by the pumps is determined directly from system demand. Pump speed control is especially appropriate for systems that are largely dominated by friction head.

Both adjustable speed drives and multiple-speed motors offer efficient system operation by driving pumps at different speeds according to system needs. During a period of low system demand, the pump is operated at low speeds, which reduces flow and lessens the burden on the throttle and bypass valves. The primary functional difference between adjustable speed drives and multiple-speed motors is the degree of speed control available. Adjustable speed drives typically modify the speed of a single-speed motor through mechanical or electrical methods, while multiple-speed motors contain a different set of windings for each speed. Adjustable speed drives are practical for applications in which flow demands change over a continuous spectrum. For more information, see the Fact Sheet titled *Controlling Pumps with Variable Frequency Drives*.

Multiple-speed pumps are practical for systems in which the flow demands change between distinct, discrete levels with lengthy periods of operation at these levels. Drawbacks to multi-speed pumps include added equipment cost and wear on the motor controllers that results from repeated energizing and de-energizing. Since each speed has its own set of motor windings, multiple-speed motors are more expensive than single-speed motors. Also, multi-speed motors are slightly less efficient than single speed motors.

Multiple-pump arrangements typically consist of pumps placed in parallel in one of two basic configurations: a large pump/small pump configuration or a series of identical pumps placed in parallel. In the large pump/small pump case, the small pump, commonly known as the **pony pump**, operates during normal conditions. The large pump is used during high demand periods. Since the pony pump is sized for normal system operation, this configuration operates more efficiently than relying on the large pump to handle loads far below its optimum capacity. For more information on this type of pump, see the Fact Sheet titled *Pony Pumps*.

With a series of identical pumps placed in parallel, the number of operating pumps can be changed according to system demands. Since the pumps are the same size they can operate together, serving the same discharge header. (If the pumps were of different sizes, the larger pumps would tend to dominate the smaller pumps and may force them to operate inefficiently.)

Each pump can be operated near its highest efficiency point. An added flow control benefit of parallel pumps is that a system curve remains the same whether one or several pumps are operating; what changes is the operating point along this system curve. Multiple pumps in parallel are well suited for systems with high static head. Another advantage is system redundancy; one pump can fail or be taken off line for maintenance while system operation is supported by the other pumps. For more information on this configuration, see the Fact Sheet titled *Multiple Pump Configurations*.

System Operating Costs

The amount of fluid power consumed by a system is a product of head and flow according to the equation:

$$\text{Fluid power} = \frac{H * Q}{3960} * \text{s.g.}$$

Where:

H = the head (ft),
Q = the flow rate (gpm),
s.g. = the **specific gravity** of the fluid,
3960 represents a units conversion to get fluid power in terms of horsepower.

The motor power required to generate these head and flow conditions is somewhat higher due to motor and pump inefficiencies. The efficiency of a pump is measured by dividing the fluid power by the pump shaft power which for a directly coupled pump motor combinations is **brake horsepower** (BHP) of the motor.

Pumps have varying efficiency levels. Centrifugal pumps have an operating point at which their efficiency is highest, commonly known as the **best efficiency point** (BEP). BEPs range widely, from 35 percent to more than 90 percent, and are a function of many design characteristics. Operating a pump at or near its BEP not only minimizes energy costs, but decreases maintenance requirements.

Systems that run continuously incur operating and maintenance costs that are large in relation to equipment purchase costs. In addition, pumps and motors are frequently oversized to provide a margin of safety against underperformance. Inefficiencies in these high-run-time systems can therefore add significantly to annual operating costs; yet, these costly inefficiencies are overlooked in the interest of ensuring system reliability. For more information on oversized pumps, see the Fact Sheet titled *Indications of Oversized Pumps*. Also, Appendix C, titled *Prescreening Motor Systems for Potential Energy Savings,* provides some guidelines for identifying and prioritizing pumping system energy reduction projects. Appendix C includes a checklist and sample data collection sheets that can be used to evaluate how well a pump is matched to its system.

The costs of oversizing pumps extend beyond the energy bill. Excess fluid power must be subsequently dissipated by a valve, pressure regulating device, or by the system piping itself, thereby increasing system wear and maintenance costs. Valve seat wear, which results from throttling excess flow and from cavitation, creates a significant maintenance problem and can shorten the interval between valve overhauls. Similarly, the noise and vibration caused by excessive flow creates stress on pipe welds and piping supports and, in severe cases, erodes pipe walls.

In effect, a common result of efforts by designers to improve pumping system reliability by oversizing equipment is reduced system reliability due to additional wear and low-efficiency operation.

SECTION 2: THE PERFORMANCE OPPORTUNITY ROADMAP

Table of Contents

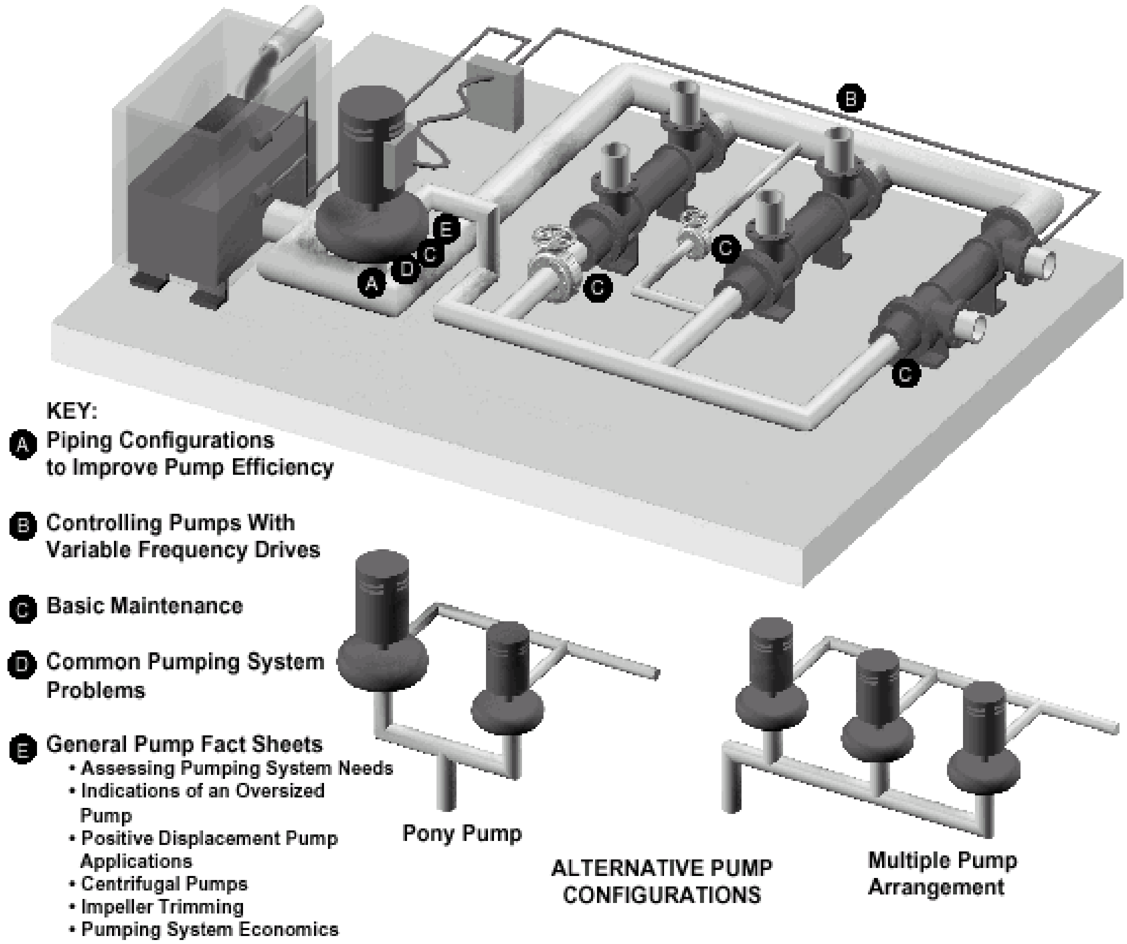
INTRODUCTION

The cost-effective operation and maintenance of a pumping system requires attention to the needs of individual equipment and the entire system. Often, operators are so focused on the immediate demands of the equipment that they overlook the broader perspective of how the system parameters are affecting this equipment. For example, the frequent replacement of pump seals and bearings can keep a maintenance crew so busy that they overlook the system operating conditions that are causing the problems in the first place. A "systems approach" analyzes both supply and demand sides of the system and how they interact; essentially shifting the focus from individual components to total system performance. The systems approach usually involves the following types of interrelated actions:

- Establishing current conditions and operating parameters;
- Determining present and estimating future process production needs;
- Gathering and analyzing operating data and developing load duty cycles;
- Assessing alternative system designs and improvements;
- Determining the most technically and economically sound options, taking into consideration all of the subsystems;
- Implementing the best option;
- Assessing energy consumption with respect to performance;
- Continuing to monitor and optimize the system; and
- Continuing to operate and maintain the system for peak performance.

The remainder of the Performance Opportunity Roadmap section of the Sourcebook is a collection of the 12 fact sheets that address both component and system issues. The following diagram shows a pump system and identifies the Fact Sheets that provide a detailed description of performance improvement opportunities.

PUMPING SYSTEM FACT SHEETS



Assessing Pumping System Needs

Pumping System Fact Sheet #1
Table of Contents

Basic Principles

There are three principal points in the life-cycle of a system that present opportunities to improve pumping system performance:

- during initial system design and pump selection;
- during troubleshooting to solve a system problem; and
- during a system capacity increase.

Analyzing System Requirements

A key to improving system performance and reliability is fully understanding system requirements (peak demand, average demand, and the variability of demand) with respect to time of day and time of year. Designing and operating systems with relatively consistent requirements are much simpler than accounting for wide demand variations.

Problems with oversized pumps often develop because the system is designed for peak loads while normal operating loads are much smaller. Excess flow energy is forced into the system which, in addition to increasing operating costs, creates unnecessary wear on components such as valves, piping, and piping supports.

Frequently, system operators do not recognize the impact of running a system at higher than necessary levels of flow and pressure. Pumps and valve lineups are set to meet the worst case demand, for example, a cooling system that is aligned to handle the largest heat load, but is not readjusted during periods of lower demand.

Many systems can be improved in terms of operating cost and reliability by increasing the awareness of system demand variability and by matching flow and pressure requirements more closely to system need.

Appendix C, titled *Prescreening Motor Systems for Potential Energy Savings*, provides an assessment tool to determine how well an existing pump is matched to its system. By providing guidelines, a checklist, and data collection sheets, this guide can assist system operators in identifying and prioritizing energy reduction opportunities in pumping systems.

Initial Pump Selection

Pump selection starts with a basic knowledge of system operating conditions: fluid properties, pressures, temperatures, and system layout. These conditions determine the type of pump that is required to meet the service needs. There are two basic types of pumps: positive displacement and centrifugal. Although axial pumps are frequently classified as a separate type of pump, their operating principles are essentially the same as centrifugal pumps.

Positive displacement pumps pressurize a fluid by squeezing it in a collapsing volume, such as in a piston. Centrifugal and axial pumps impart kinetic energy to a fluid and rely on conversion of this kinetic energy to potential energy to increase fluid pressure. In general, positive displacement and centrifugal pumps serve different applications.

Centrifugal pumps are used in high flow, low head applications in which fluid viscosity is not prohibitively high. In contrast, positive displacement pumps are used in low flow, high head applications and with high-viscosity fluids. However, there are many exceptions to these guidelines. For more information on the factors which determine the feasibility of positive displacement and centrifugal pumps, see the *Introduction to Pumping Systems*, the *Centrifugal Pumps* Fact Sheet, and the *Positive Displacement Pumps* Fact Sheet.

Pumps are usually selected on a "best fit" basis rather than designed specifically for a particular application. A pump is chosen from a wide range of types and models based on its ability to meet the anticipated demands of a system. Pumps have two mutually dependent outputs: rate of flow and head. The variability of these outputs and other factors, such as efficiency, operating life, and maintenance, complicate the pump selection process.

Tendency to Oversize

Centrifugal pumps are by far the most popular type of pump because they are typically low cost, have low maintenance requirements and long operating lives. Despite their extensive use, the complexity of selecting a centrifugal pump creates a tendency to oversize it. In an effort to accommodate uncertainties in system design, fouling effects, or future capacity increases, designers often select larger-than-necessary pump/motor assemblies. Designers also tend to oversize to protect against being responsible for inadequate system performance.

Unfortunately, oversizing a pump increases the costs of operating and maintaining a pumping system and creates a different set of operating problems including excess flow noise, inefficient pump operation, and pipe vibrations. The energy cost alone of using an oversized pump is substantial. For more information on this problem, see the Fact Sheet titled *Indications of Oversized Pumps.*

Troubleshooting a System Problem

Some pumping system problems are sufficiently expensive to justify a system assessment. Examples of these problems include inefficient operation, cavitation, poor flow control, and high maintenance.

Inefficient Operation

Inefficient system operation can be caused by a number of problems such as improper pump selection, poor system design, excessive wear ring clearances and wasteful flow control practices. Indications of inefficient system operation include high energy costs, high flow noise in pipes and across valves, and high maintenance requirements.

Each centrifugal pump has a best efficiency point (BEP), at which its operating efficiency is highest and its radial bearing loads are lowest. At its BEP, a pump operates most cost-effectively both in terms of energy efficiency and maintenance considerations. In reality, continuously operating a pump at its BEP is difficult because systems usually have changing demands. However, selecting a pump with a BEP that is close to the system's normal operating range can provide significant operating cost savings.

Cavitation

Centrifugal pumps are susceptible to a damaging and performance-degrading effect known as cavitation. Cavitation occurs when the vapor pressure of a fluid exceeds its static pressure. The fluid vaporizes in the form of tiny bubbles, then, when the surrounding pressure increases, the fluid returns to liquid as these tiny bubbles collapse violently. The collapse of the bubbles sends high velocity water jets into surrounding surfaces causing impeller damage and the erosion of pump casing and piping surfaces. A cavitating pump experiences accelerated bearing and seal wear, and poor performance.

Cavitation usually occurs at high flow rates, when a pump is operating at the far right portion of its performance curve. However, cavitation-like damage can also occur at low flow rates, when damaging vortices develop in the pump. The presence of cavitation is indicated by crackling and popping noises, similar to the sound of marbles flowing through the pipe. If uncorrected, cavitation can lead to expensive repairs. For more information on cavitation, see the Fact Sheet titled *Common Pumping System Problems*.

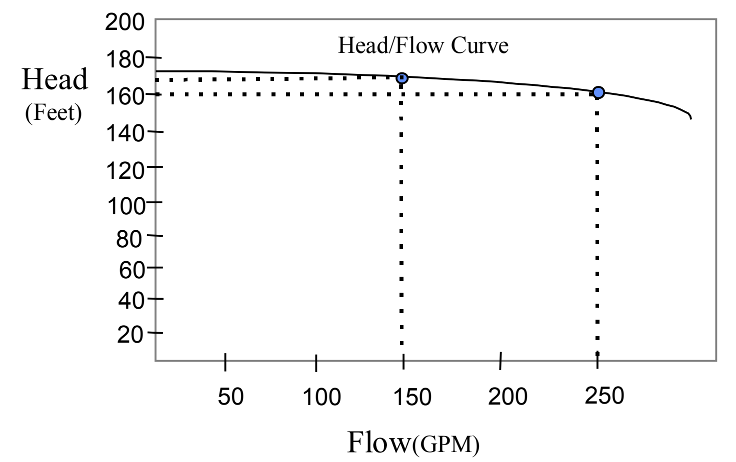


Figure 1 Demonstrating the Sensitivity of Flow to Changes in Backpressure

Internal Recirculation

Internal recirculation is another performance degrading effect that damages pumps in a similar manner as cavitation. Internal recirculation tends to occur at low flow rates when fluid leaving the impeller forms damaging vortices. To avoid this problem, manufacturers list minimum flow rates for their pumps. Operators should be aware of this minimum flow requirement and avoid overly restricting pump output.

Poor Flow Control

Poor flow control can result from several conditions, including improper pump selection and poor system design. Some pumps have performance curve characteristics that require careful consideration of the variability in the operating requirements. Pumps with performance curves that are relatively flat or those that "droop" at low flow rates should be selected with an awareness of the full operating demands on the pump.

Generally, head curves arc downward from the zero flow condition - that is, as the backpressure on the pump decreases, the flow increases (see Figure 1). The specific slope and shape of the curve are largely dependent on the shape of the impeller vanes and the pump speed.

The slope of the pump curve determines the response of the pump output to changes in backpressure. A flat pump curve responds to small decreases in backpressure with large increases in flow. This sensitivity can lead to system instability, especially in systems that have substantial changes in throttle or bypass valve positions. For example, in the pump curve of Figure 1, at 160 feet of head and 250 gpm flow a 10 foot increase in system backpressure results in a 100 gpm drop-off in pump flow.

Additionally, some pumps have performance curves that droop at low flow rates. This characteristic primarily applies to pumps with low specific speeds. As shown in Figure 2, these pumps have performance curves that point upward at low flow rates. Since system curves also point upward, the system curve and the pump curve can intersect at more than one point which leads to instability. In some cases, pumps operating in this range will hunt, that is, repeatedly adjust its output as it searches for a stable operating point. Although most manufacturers will publish a minimum flow requirement to prevent a design engineer from specifying a pump that operates in this region, pumps may wear out allowing their operating points to drift into this region. Operators should be aware that surging pump operation may be the combined result of deteriorating pump condition and a drooping head curve.

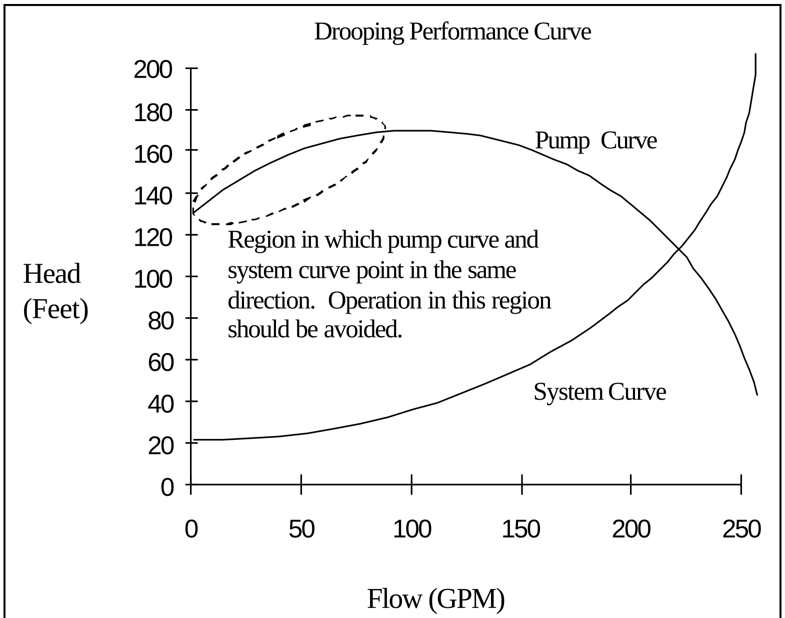


Figure 2 Drooping Performance Curve

Excessive Maintenance

All pumping systems require some maintenance; however, systems with unusually high maintenance requirements are often the result of improper design and operation.

Problems such as cavitation, frequent energization and de-energization of a pump, and valve seat leakage can decrease the length of time between repairs. A system's maintenance requirements can be measured by the mean time between failure (MTBF) for its components. Since systems have a broad range of service environments, it is difficult to characterize the MTBF for each system component; however, manufacturers of seals and bearings will often provide an estimated MTBF for a particular product. If the actual MTBF is much less than the manufacturer recommended interval, then an assessment of the failure's cause should be made.

Bearing replacement

There are two principal types of bearings in centrifugal pumps, thrust and radial. The operating conditions have a large impact on the amount of load each type of bearing sees and the rate at which the bearings wear. To assess whether bearings are enduring comparatively well, the histories of other pumps in similar environments should be evaluated. If bearings require replacement every few months, then system operating conditions or the design criteria for the bearings should be evaluated. Factors that accelerate bearing wear are high loads, poor lubrication, high operating temperatures, and vibrations. Preventive maintenance techniques such as vibration analysis and oil analysis can improve the effectiveness of scheduling bearing replacements. For more information, see the Fact Sheet titled *Common Pumping System Problems*.

Packing/mechanical seal replacement.

Packing and mechanical seals are alternative methods of sealing leakage around the pump shaft penetration into the pump casing. Packing is less expensive and commonly used when leakage from the pump is not costly or otherwise problematic. Mechanical seals are more effective at sealing fluid but are more expensive and require greater maintenance.

Packing squeezes against the pump shaft and requires frequent adjustment to maintain the proper amount of cooling and lubrication leakage. Packing life depends on the service conditions, the quality of the packing material, and on the care with which it is installed and adjusted.

Assessing and troubleshooting mechanical seal performance is complicated by the wide range of factors that impact the function and operating life of mechanical seals. Since there are many different types of mechanical seals for many different applications, it is difficult to characterize how long a seal should last. Common causes of seal problems include contamination of the seal faces, overheating due to inadequate lubrication, and improper installation. For more information on mechanical seal and packing problems, see the Fact Sheet titled *Common Pumping System Problems*.

Wear Ring Clearances

Wear rings are used in centrifugal pumps to establish clearances between impellers and pump casings or other impellers. As pumps operate, over time erosion from abrasive particles or from fluid squeezing through the gaps can increase these clearances. The consequence of increasing these gaps is greater leakage within the pump. That is, more fluid passes from the high pressure side of an impeller to its low pressure side which reduces pump efficiency.

Setting the proper gaps in the wear ring should be done in accordance with manufacturer instructions at initial pump installation. Some pumps are furnished with wear rings while others require the user to procure, machine and install wear rings to establish the correct clearances. This same practice should be performed during major pump overhauls or if pump performance falls off.

Electrical System Wear

The stress on a motor and its supporting electrical equipment is minimized when a motor is started under its lowest mechanical load. For a radial centrifugal pump, the brake horsepower curve is typically a constantly increasing line indicating that the motor current increases as the flow rate goes up. A practical implication of a constantly rising BHP line is that the pump's mechanical load is smallest at zero flow, that is, when all the valves downstream of it are closed. Consequently, starting a centrifugal pump while it is deadheaded and then opening the valves soon after the pump comes up to speed can reduce electrical stresses on the motor and the motor controller.

For an axial pump, this relationship between flow and power is reversed. In an axial pump, power decreases as flow increases. Consequently, soft starting axial pumps requires ensuring downstream valves are open until the pump is up to speed.

The issue of startup procedures requires consideration of many factors. In some systems, the effect of pump starts on the fluid system itself is a larger concern than the impact on the electrical system. For example, rapid acceleration of large volumes of fluid can create damaging water hammers. However, as far as the electrical system is concerned, startup practices and, in some cases, special soft starting switchgear that minimize electrical surges and high starting currents, can extend the operating life of the system and improve overall system reliability.

System Capacity Increase

For a system that is to be modified or upgraded, an assessment of the available pumping capacity should be performed. Unless the existing pump is considerably overdesigned, adding a branch to a system or increasing the flow to an existing component requires that a larger pump or an additional pump must be installed. Usually, the type of pump that to is to be installed is the same type as the existing pump. However, the size of the new pump or pumps can vary according to the service needs.

In some cases, a large pump capable of handling the highest system demand can be equipped with a variable frequency drive (VFD) to ensure it operates efficiently over a wide range of system conditions. VFDs are especially practical for systems that are largely dominated by frictional resistance; however, they must be cautiously evaluated for use in systems that have high static head. In high static head systems, reducing pump speed can cause a pump to operate close to shutoff head conditions which generally leads to poor performance or, in severe cases, damage. For more information, see the Fact Sheet titled *Controlling Pumps with Variable Frequency Drives*.

Alternatively, expanding pumping system capacity can be accomplished using multiple pump arrangements. Multiple pump arrangements allow several pumps to be available to serve a system. System flow requirements dictate the number of pumps energized at any particular time. The principal benefit of this alternative is to keep each pump operating closely to its BEP, rather than requiring one large pump to operate over a wide range of conditions. Multiple pump arrangements are well suited for systems that have high static heads. Unlike alternatives that reduce pump speed, the use of multiple pumps in parallel avoids the danger of operating a pump near shutoff head and can allow each pump to operate more efficiently. For more information, see the Fact Sheet titled *Multiple Pump Arrangements*. Another multiple pump application is the use of two different size pumps: a small one, known as the pony pump, to handle normal loads and a large one to handle worst case loads. The advantage of using a pony pump is that the smaller pump can be sized for efficient operation during normal conditions which allows lower operating and maintenance costs. For more information, see the Fact Sheet titled *Pony Pumps*.

Common Pumping System Problems

Pumping System Fact Sheet #2
Table of Contents

Poor design and improper system operation can create problems in both pumps and pumping systems. As rotating equipment, pumps are subject to wear, erosion, cavitation, leakage, etc.; consequently, they require considerable maintenance. However, there are also many pumping system problems that are the result of improper pump selection and operation.

System Problems

Many pumping systems consist of components which are not dynamic. That is, they allow fluid or heat transfer but, outside of thermal expansion or structural vibration, are not moving and do not have dynamic surfaces that wear out. (Hydraulic systems are a notable exception, but they have a unique set of operating problems.) The most common types of problems in these pumping systems are leakage, fouling, valve failure, and pipe support cracking.

Leakage

In most systems, leakage will first occur at mechanical joints. Once they have been hydrostatically tested (pressurized higher than system operating pressure and inspected for leaks), solid pipe and welded joints do not typically develop leaks unless the pipe walls erode. Mechanical joints rely on fastener tension to insure tightness. Over time, these joints can loosen or the gasket material can degrade. Repair of a leaking mechanical joint can be as simple as tightening the joint fasteners or as difficult as disassembling the joint and replacing the gaskets or "O" rings.

Causes of mechanical joint leakage include pipe sag due to inadequate support, thermal strain, and fluidborne and structureborne vibrations. Since improper pump selection and operation can induce high vibration levels in system, a pump problem can quickly become a pumping system problem.

Valve Problems

Valves are susceptible to wear and leakage and require a large amount of maintenance. Occasionally, they must be overhauled depending on the service environment. Valves are often installed in a pumping system using bolted flange connections. These valves can experience the same leakage problems as mechanical joints.

Additionally, valve packing can develop leakage. Much like the packing used in pumps, valve packing controls leakage around a valve stem. Leakage at this packing can result from improper

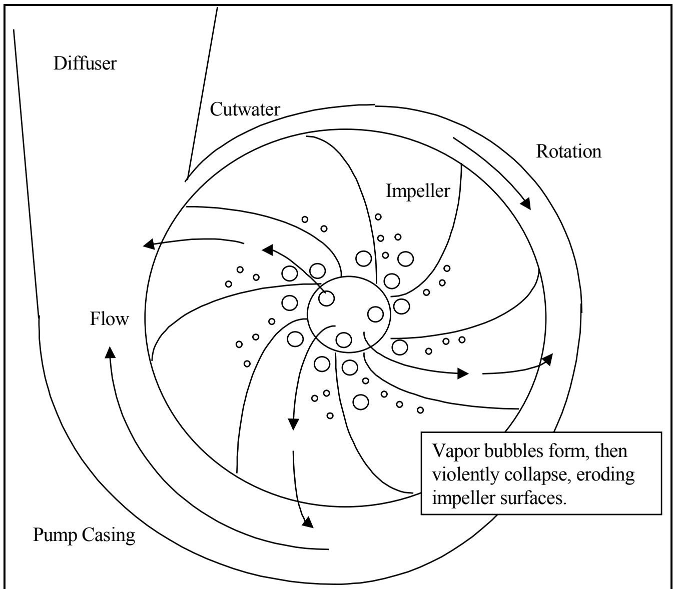


Figure 1 Cavitation in a Centrifugal Pump Impeller

packing installation, and packing degradation. In some systems, a little leakage from around valve stems is not a problem. In other systems, such as those with toxic fluids, such leakage requires immediate attention.

In many systems, during initial operation, valve packing leakage is allowed until the valves are opened and shut enough times to wear in the packing. Also, in high temperature systems such as steam systems, valve packing may leak at low temperature then seal at high temperature as the valve heats up and expands.

Adjustments to valve packing should be made cautiously. Overtightening a valve packing gland can significantly increase the amount of torque required to operate a valve. If the packing is too tight, the valve handwheel torque may be too high to turn by hand posing a potential safety problem.

Valve seat wear is another problem that can be worsened by improper pump selection. Valve seats form the seal that allows a valve to stop flow. The internal surfaces of these seats are classified as "hard" or "soft" depending on their material type. Soft seated valves usually have some sort of polymer coating on the seating surface while hard seated valves are usually formed by metal-to-metal contact. Soft seated valves tend to seal more tightly but wear more quickly than hard seated valves.

Valve seats suffer wear problems from erosive fluids and high velocity flow. Oversizing a pump can create high pressure drops across throttle valves and high flow rates through bypass valves. In both cases, the valve seats may wear quickly, shortening the intervals between valve overhauls.

Pipe Supports

In general, unless a system is poorly designed, the hangers that hold piping and the foundations that support system equipment should last the life of a system. However, high vibration levels can create fatigue loads that cause structural members to crack. Pumps that are substantially oversized can induce such vibrations.

Centrifugal Pump Problems

Among the more attractive advantages of centrifugal pumps are their simple operation, reliability, and long life. In order to realize these benefits, however, problems such as cavitation, internal recirculation, seal or packing wear, poor material selection, and improper shaft loading must be avoided.

Cavitation and Internal Recirculation

Cavitation is a damaging condition which erodes pump impellers, shortening their operating lives and, in the process, accelerating the wear rate of bearings and seals. Shown in Figure 1, cavitation is both a problem itself and an indication of poor system performance.

Cavitation occurs when the fluid's vapor pressure exceeds the fluid pressure. In centrifugal pumps, the acceleration of fluid into the impeller causes the fluid pressure to drop. If this pressure drop is sufficient, the fluid vaporizes, forming tiny bubbles which are unstable and prone to violent collapse. These violent bubble collapses can throw tiny, destructive water jets onto impeller surfaces.

Crackling and popping noises that often sound like marbles passing through the pump are indications of cavitation. Cavitation can be caused by improper pump selection or operating the system at either higher-than-design temperatures or lower-than-design suction pressure. Usually, cavitation occurs at high flow rates, when a pump is operating far to the right along its performance curve; however, under certain conditions, cavitation damage can occur at low flow rates as well.

Cavitation damage can also result when the pump suction is starved due to air pocket formation or pipe fouling. The most important effects of sustained cavitation are reduced pump performance and erosion of the pump impeller. Cavitation degrades pump performance because the presence of vapor in the pump restricts flow and lowers the generated head.

If cavitation causes sufficient material loss in impellers, they can become unbalanced, creating alternating bearing loads which accelerate bearing wear. By dramatically shortening pump life, cavitation is a serious threat to system reliability. Cavitation also increases other maintenance requirements by inducing vibrations which stress pump foundations and connected piping.

Cavitation-like damage can also occur due to internal recirculation. Operating the system at low flow rates can establish damaging flow patterns in either the suction or discharge regions of an impeller.

For applications in which cavitation is, to some extent, unavoidable, high tensile strength materials should be specified for the impeller. Stronger materials can withstand higher energy cavitation; however, caution should be used when sourcing materials to ensure compatibility with the system fluid. (For example, stainless steel, though strong, is subject to corrosion-induced cracking in salt water.)

Seal/Packing Problems

The point at which the shaft penetrates the pump casing, known as the stuffing box, provides a leak path which must be sealed. This area is normally sealed using packing or mechanical seals (see Figure 2). For systems in which fluid leakage is not a significant concern, packing is usually used because it is much less expensive and requires less sophisticated maintenance skills. Mechanical seals provide superior sealing but are typically more expensive and harder to repair/replace.

Packing

There are two basic types of packing problems: overtightening and improper installation. Packing typically requires some leakage in order to remain lubricated and cooled. If packing rings are overtightened, friction between the packing and shaft will generate excessive heat that can destroy the packing and possibly damage the shaft.

Since packing directly contacts the pump shaft, it wears over time, allowing the leakage rate to increase. Consequently, the packing gland must be periodically tightened to squeeze the packing against the shaft to bring leakage down to an acceptable level. Improper packing installation leads to uneven compression of the packing rings (overtightening of one, insufficient tightening of others) or an overly loose fit between the packing and shaft. This often results in excessive leakage, which can cause housekeeping problems (wet floors), high ambient moisture levels, and, if the fluid is toxic, contamination problems. Moreover, if the fluid is expensive, leakage has a direct economic cost.

If the fluid pressure at the stuffing box is below atmospheric pressure, then improper packing seal installation can allow air to enter the system. Pulling air into the suction region can degrade pump performance up to 3 percent or more. Also, for systems that require precise fluid chemistries, especially those that are sensitive to oxygen content, pulling in air can contaminate the system.

Mechanical Seals

Mechanical seals are typically used in applications for which superior sealing is required. The effectiveness of mechanical seals is highly dependent on correct installation and maintaining a clean operating environment. Mechanical seals have two primary failure mechanisms: degradation of the face materials; and loss of spring or bellows tension, which allows the faces to separate more easily. Degradation of the seal face is usually caused by debris that wedges into a seal face and causes damage. To minimize the risk of this type of damage, mechanical seals are often serviced by special flushing lines that have filters to catch debris.

Seal faces are held together by a force that is usually provided by springs or bellows. Fatigue, fouling, and/or corrosive environments, which degrade spring and bellows materials, often cause the loss of compressive properties. To minimize fatigue loads on mechanical seals, the seal must be precisely aligned such that spring movement is minimal during each shaft revolution. In systems with highly corrosive fluids, mechanical seals with external springs are recommended.

The face materials require an alignment which has tolerances on the order of microns (one-millionth of a meter). The precise flatness and proper alignment of the seals is important because these faces must remain in constant contact as the pump shaft spins. Since pumps often rotate at 1800 or 3600 rpm, even slight variations in the contact between two seal faces can quickly destroy a seal's effectiveness.

Shaft Deflection

Shaft deflection is a problem among long-shafted centrifugal pumps. Shaft deflection is caused by the force resulting from an unequal pressure distribution around an impeller. The side of the impeller that is nearest the pump discharge connection sees a higher pressure than the other side of the impeller, creating a radial force on the shaft. Some pumps are equipped with multiple volutes to minimize this imbalance.

In general, shaft deflection is most problematic when a pump is operated at low flow conditions. The consequences of severe shaft deflection include high wear rate on bearings, shaft seal leakage, and fatigue bending of the pump shaft. Although pump shafts are typically designed to last the life of the pump, severe shaft deflections can load shafts in ways that they were not designed to handle. If sustained for extended periods of operation, severe shaft deflections can result in the catastrophic failure of a pump shaft.

Pump shaft failure is costly and can require replacement of the entire pump. The risk of shaft failure is particularly prevalent in pumps that have relatively long distances between shaft bearings. Operating these pumps at or near their minimum flow conditions for extended periods greatly increases the chances of pump shaft failure.

Positive Displacement Pump Problems

Positive displacement pumps have a different set of problems than centrifugal pumps. In many positive displacement pumps, the cyclical nature of the pumping action fatigues components such as bearings and diaphragms. Also, since their flow rate is essentially independent of backpressure, positive displacement pumps incur an inherent risk of overpressurizing the discharge piping. If valves in the pumping system are aligned such that the discharge lines downstream of a pump are all closed while the pump is operating, then over pressure conditions can be quickly reached. In such cases, if a pressure relief mechanism is not activated, the pump motor will either reach its lockout torque or the pressure will build until some part of the system fails or ruptures.

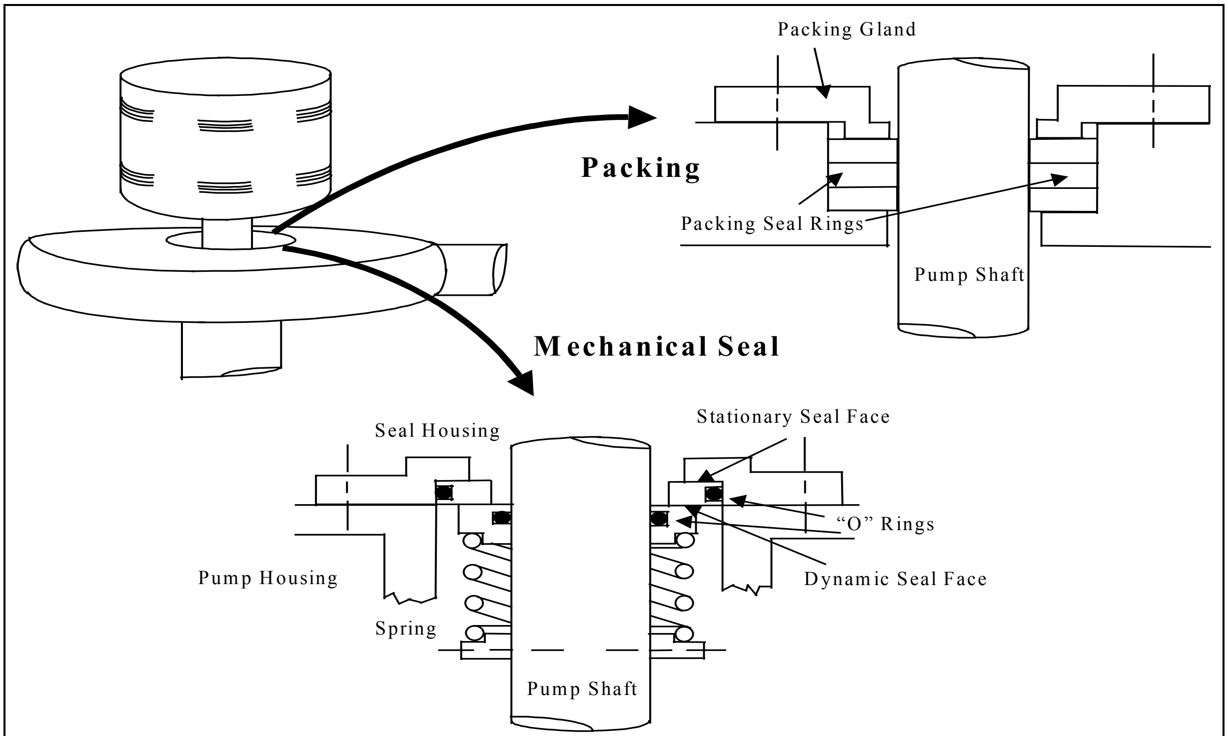


Figure 2 Two Types of Sealing methods: Packing and Mechanical Seals

This danger creates the need for the installation and maintenance of pressure relief valves. Failure of these valves to operate properly can result in catastrophic system damage. A proper maintenance program to check these valves should therefore be rigorously followed.

A characteristic of many positive displacement pumps is pulsating flow. The fluid-borne and structure-borne vibrations resulting from these pulsations can create load conditions that hasten the degradation of piping, valves, and piping supports. Consequently, pumping systems that are not designed to handle the vibration loads of positive displacement pumps may suffer severe operating and maintenance problems.

Indications of an Oversized Pump

Pumping System Fact Sheet #3
Table of Contents

The Tendency to Oversize Pumps

Conservative engineering practices often result in the specification, purchase, and installation of pumps that exceed the requirements of the system. Engineers often include a margin of safety in sizing pumps to compensate for uncertainties in the design process. Anticipated system capacity expansions and potential fouling effects add to the tendency to source pumps that are "one size up" from those that meet the system requirements.

Unfortunately, oversizing pumps adds to system operating costs both in terms of energy and maintenance requirements--costs that are often overlooked during the system specification process. Since many of these operating and maintenance costs are avoidable, correcting an oversized pump can be a cost-effective system improvement.

Appendix C, *Prescreening Motor Systems for Potential Energy Savings*, describes how to identify and prioritize pumping system energy reduction projects. Using many of the principles discussed in this fact sheet, the prescreening guide outlines several screening methods that can determine whether a pump is operating efficiently relative to the needs of its system.

Indications of Pump Oversizing

There are five common indications of pump oversizing.

High Flow Noise

Oversized pumps tend to create high noise levels. These problems are frequently disregarded as normal system operating characteristics as the operators simply get used to the system's acoustic levels. Unless the noise levels worsen, the system is assumed to be performing normally. However, the cumulative damage that results from flow-induced pipe vibrations can significantly accelerate system wear.

Pipe vibrations tend to loosen flanged connections and other mechanical joints, and create fatigue loads on welds in both the pipes and piping supports.

Highly Throttled Flow Control Valves

Throttle valves affect system flow in two principal ways:

- Shifting system flow balance, forcing flow rates in different system branches to increase or decrease.
- Changing the overall system backpressure - essentially causing the pump to "see" a different system, which shifts its operating point along its performance curve.

Both these effects occur concurrently to an extent that depends on the system's configuration. In systems with oversized pumps, valves tend to remain in restrictive positions, which forces the pump to operate against a high backpressure. Since this backpressure is typically higher than the pressure associated with the pump's best efficiency point (BEP), the pump operates inefficiently and is susceptible to higher than normal bearing wear.

Heavy Use of Bypass Lines

In some systems, excess flow is handled by bypass lines around system equipment. Bypass lines prevent the buildup of damaging pressure differentials and are used for temperature control in many heat exchangers. Unfortunately, the energy used to push fluid through bypass lines is wasted. A system that normally operates with a large number of open bypass valves indicates that the system is performing inefficiently due to improper balancing, oversized pumps, or both.

Frequent Bearing and Seal Replacement

The penalties for excess system flow can extend beyond high energy costs to include frequent pump maintenance. Since oversized pumps generate high backpressures, they often operate far to the left of their BEP and tend to experience greater bearing and seal wear. The higher backpressure caused by increased flow velocity creates high radial bearing and thrust bearing loads and greater pressure on mechanical seals and packing glands.

Intermittent Pump Operation

Pumps are often used to maintain fluid levels in tanks, either by filling or draining them as necessary. Many systems rely on a level control system to activate the pumps automatically. The cumulative effect of energizing and de-energizing a pump shortens the lives of the motor controller and the pump assembly. In addition, an oversized pump generates higher friction losses during operation since it pushes fluid through the piping at higher velocities.

Corrective Measures

In systems served by oversized pumps, there are several corrective measures that can lower system operating costs and extend equipment maintenance intervals. The choice among these measures depends on the system and on the particular indicator that points to the oversized pump problem. An obvious remedy is to replace the pump/motor assembly with a downsized version; however, this effort is costly and may not be feasible in all situations. Alternatives to replacing the entire pump/motor assembly include:

- Replace the impeller of the existing pump with a smaller impeller,
- Reduce the outside diameter of the existing impeller,
- Use an adjustable speed drive (ASD) motor to operate the pump,
- Add a smaller pump to reduce the intermittent operation of the existing pump, and
- Appropriate use of flow control valves.

Impeller Adjustments

Most pumps can be assembled with more than one impeller diameter. Pump manufacturers standardize their pump models as much as possible to lower production costs; consequently, casings and pump shafts can accommodate multiple impeller sizes. This characteristic often allows a smaller impeller to be used in applications for which the existing impeller generates excessive flow or head.

For applications in which a smaller impeller is not available or in which the performance of the next smallest impeller is insufficient, impeller trimming offers an alternative. Impeller trimming reduces the impeller diameter so that, using the same constant speed pump motor, the impeller tip speed is decreased. Since the head generated by a pump is a function of its tip speed, impeller trimming shifts the entire performance curve of the pump downward and to the left. For more information on this performance improvement opportunity, see the Fact Sheet titled *Impeller Trimming*.

Use of Variable Frequency Drives

Pumps that see variable demand conditions, forcing them to operate over a wide range of their performance curves, are often attractive candidates for adjustable speed drives (ASDs). The most popular type of ASD is the variable frequency drive (VFD). VFDs use electronic controls to regulate motor speed which, in turn, adjusts the pump output. The principal advantage offered by VFDs is improved matching between the fluid energy required by the system and the energy delivered to the system by the pump. As the system demand changes, the VFD adjusts the pump speed to meet this demand, reducing the energy lost to throttling or bypassing excess flow. The energy and maintenance cost savings provide a return which often justifies the VFD investment. However, VFDs are not practical for all applications, for example, systems with high static head and systems that operate for extended periods under low flow conditions. For more information, see the Fact Sheet on *Variable Frequency Drives*.

Use of Smaller Pumps to Augment Larger Pumps

Pumps that maintain fluid levels in tanks or reservoirs are often sized according to the worst-case or peak service conditions. Since the worst-case conditions are often significantly worse than normal operating conditions, many pumps are oversized relative to the demands of their application for most of their operating lives. The penalties of using oversized pumps include frequent pump energization and de-energization, operation away from the pumps' BEP, and high friction losses -- all of which add to energy and maintenance costs.

The addition of a smaller pump to handle the normal system demand relieves the burden on the larger pump, which can be energized as needed during high load conditions. A smaller pump would operate more efficiently and would require less maintenance. For more information, see the Fact Sheet on *Pony Pumps*.

Piping Configurations to Improve Pumping System Efficiency

Pumping System Fact Sheet #4
Table of Contents

Basic Principles

Optimizing the configuration of a pumping system requires the consideration of many factors such as proper pipe size, a piping system layout that minimizes pressure drops, and low-loss components. To determine the proper pipe size, designers must balance the initial cost of the pipe against the costs of pushing fluid through it. Larger pipes create less friction loss for a given flow rate; however, the larger pipes have higher material and installation costs. Unfortunately, designers often overlook the energy costs of using small piping and size system piping with an initial cost focus.

System piping similarly should be configured with an awareness of the energy costs associated with poor flow profiles. Although piping system layouts are usually dictated by space constraints, there are often opportunities to minimize unnecessary pressure drops by avoiding sharp bends, expansions, and contractions and, where possible, keeping piping as straight as possible. For example, orienting valves and system equipment so that they are in-line with the pipe run is one useful rule of thumb.

The use of low-loss components provides another opportunity to minimize life cycle costs during system design. As with pipe sizing, the same principle of balancing initial costs with future energy costs is required. For example, system components such as valves are sometimes selected without regard to life cycle cost.

In many cases, the selection of a particular valve type is guided by service requirements such sealing capability under various pressures, the number of times it is opened and closed, handwheel torque, and the consequences of valve stem leakage. However, there are applications where the service requirements are comparatively light, and the valve is selected on a first-cost basis at the expense of high flow loss. For example, globe valves are commonly selected due to their low cost and simplicity. However, these valves have a relatively high flow loss coefficient due to the flow path through the valve. Although valve selection requires the consideration of many factors, including the cost of flow losses among these factors can improve system life cycle costs.

Pump Concerns

Since centrifugal pumps operate most effectively when the inlet flow has a uniform profile, systems should be designed to avoid non-uniform flow at the pump inlet. In centrifugal pumps, as fluid moves from the suction piping into the impeller eye, it gets caught by an impeller vane and then accelerates to the tip. If flow into the impeller eye is uneven, the impeller transfers

energy to the fluid less efficiently. Additionally, uneven flow at the pump suction promotes excessive vibrations which shorten pump life and weaken pipe welds and mechanical joints.
Poor pump performance, improper flow profile, vapor collection, and vortex formation are three common pipe configuration problems. Figure 1 depicts common piping installation problems and shows the corresponding proper arrangements.

Poor Flow Profile

Piping configurations often promote uneven flow. Elbows and valves, placed just before the pump, disrupt fluid flow and degrade pump performance. This problem is particularly significant when the flow velocity is high and the suction pressure is low. Under these conditions, dramatic flow redirection -- commonly created by a small-radius elbow or a globe valve -- promotes highly turbulent flow which diminishes pump performance.

Vapor Collection

Vapor entrapment can be another consequence of poor piping layout. If the suction piping leading to the pump does not have a constant slope, vapor can collect at the high points. Vapor pockets limit flow through the pipe and cause pressure pulsations that degrade pump performance. Figure 1 demonstrates examples of piping installations that encourage vapor collection.

Vortex Formation

In tank applications, if a fluid surface drops close to the suction inlet, a vortex can form, potential creating a loss of suction head or allowing air into the pump. In severe cases, the pump will lose its prime, causing severe performance degradation and risking damage. A centrifugal pump is not designed to run without fluid; if unlubricated, the mechanical seals, packing, and impeller wearing rings become susceptible to damage. Most centrifugal pumps are not self-priming, if a pump loses its prime, it must be filled and vented in order to be restarted. (Although some centrifugal pumps are self-priming, they tend to be less efficient than conventional centrifugal pumps and should be used only when necessary.)

Rules of Thumb For Improving Pipe Configurations

There are two primary rules of thumb for improving pipe configurations. First, to establish a uniform-velocity flow profile upstream of a pump, a straight run of pipe should lead into the pump inlet. If space constraints require the use of an elbow just upstream of the pump, a long radius elbow should be selected. In some cases, a flow straightener, such as a baffle plate or a set of turning vanes, should be installed in conjunction with an elbow to correct the flow disruption (see Figure 2). By smoothing out the flow, a flow straightener creates a more even velocity profile. Care must be exercised, however, to ensure that the pressure drop across the straightener does not create cavitation.

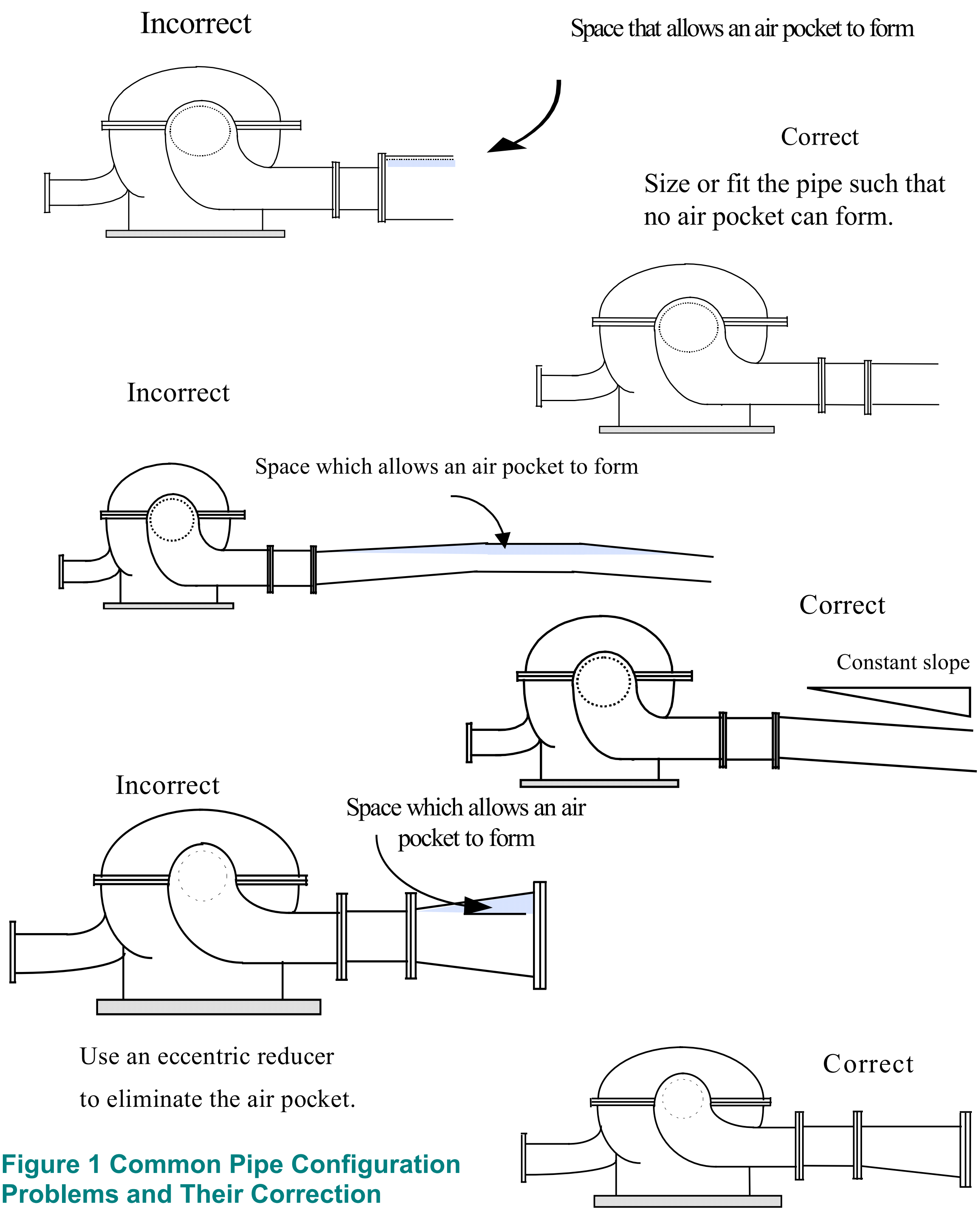


Figure 1 Common Pipe Configuration Problems and Their Correction

The second consideration is that suction piping should be sized as large as possible to minimize friction losses. An appropriate guideline to sizing suction piping is to limit fluid velocity to 5 feet per second. Minimizing head losses on the inlet side of a pump lowers the risk of cavitation.

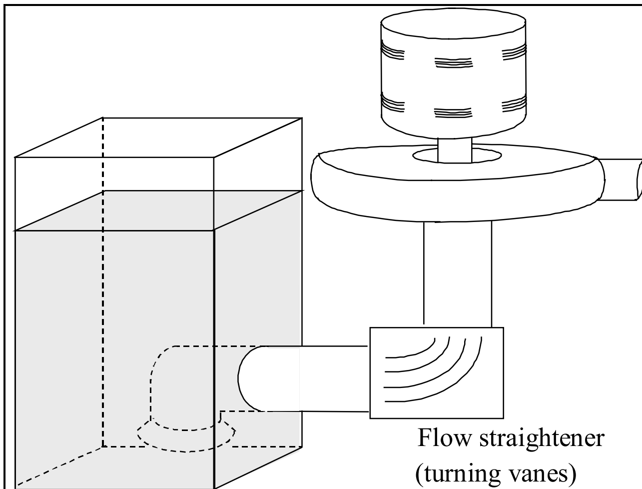


Figure 2 Flow Straighteners

In addition, transition pieces and joints between pipes or fittings should be kept as smooth as possible, since burrs or misaligned pipes create trip points for flow disruption. Suction and discharge piping close to the pump should be properly supported (see Figure 3). Many pump/motor problems are caused by pipe reactions which pull the pump out of alignment. For example, upon installation of a pump, the connecting piping is rarely perfectly aligned to the pump; some amount of mechanical correction is needed to make the connections. If the piping is pulled too far from its relaxed position to make the fit up, it can force the pump and motor out of alignment, excessively straining the pump casing.

By properly supporting the piping near the pump, the pipe reaction is carried by the pipe hangers rather than the pump itself. Also, proper support of the piping near the pump stiffens the system which can reduce system vibrations.

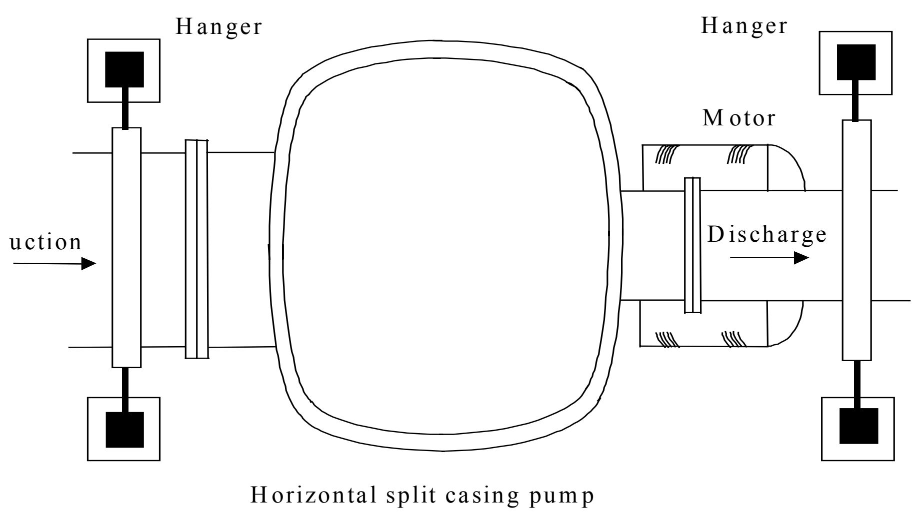


Figure 3 Proper Support of Suction and Discharge Piping

Basic Maintenance

Pumping System Fact Sheet #5
Table of Contents

Maintenance Items

Although centrifugal pumps are widely used due to their low maintenance requirements, as with all machinery, they do require periodic maintenance. Common maintenance tasks on centrifugal pumps include:

- Bearing lubrication and replacement,
- Mechanical seal replacement,
- Packing tightening and replacement,
- Wear ring replacement,
- Impeller replacement,
- Pump/motor alignment, and
- Motor repair or replacement.

Common Failures

The most costly consequence of improper pump maintenance is unscheduled downtime. Causes of this downtime vary according to the demands of the application. In corrosive or hazardous fluid systems, mechanical seal leaks often warrant system shutdown for safety reasons. In other systems, such leaks can be tolerated. In yet other systems, problems such as bearing seizures may pose the largest threat to continuous system operation. Since each system places particular demands on its pump/motor equipment, maintenance requirements vary widely.

Maintenance Schedules

To minimize unscheduled downtime, basic system maintenance should be performed at pre-determined intervals. Factors that weigh into this schedule should be the cost of downtime, the cost and the risk of catastrophic failure, the expected mean time between failure (MTBF) for motors, bearings, and seals, and the availability of backup equipment. Hours of operation or calendar periods, such as quarterly or semi-annual, can serve as the interval determinant. A sample basic maintenance checklist is shown below.

The decision of how frequently to perform maintenance should be based on manufacturer recommendations and experience with pumps in similar applications. In systems that do not have abnormally severe operating demands, a typical maintenance schedule should include:

Packing and Mechanical Seal Adjustments

Packing and mechanical seal adjustments should be performed weekly, taking into consideration the following:

- For packing, adjust the tightness of the gland bolts to obtain the cooling flow leakage rate allowed by the pump manufacturer (usually 2 to 60 drops per minute). Do not over tighten as this will burn up the packing and require re-packing the stuffing box. As packing wears, more packing rings may be added. Eventually, stuffing box will need to be packed with all new packing rings. When repacking the box, clean and lubricate the gland bolts.
- For mechanical seals, check seal performance and measure leakage (one to four drops per minute may be allowed by the seal manufacturer).

Bearing Lubrication

Bearing lubrication should be performed semi-annually or annually. Particular attention should be paid to the following:

- For grease lubricated bearings, add grease as required by the pump technical manual. Be careful not to over grease bearings as this interferes with ball or roller motion and may cause overheating.
- Check the grease quality and, if necessary, repack the bearings.
- For oil lubricated bearings, check the oil level and quality. If necessary, add or replace the oil. Again, do not overfill the oil reservoir.

Basic Maintenance Checklist

- ☐ Packing. Check leakage around the packing and adjust in accordance with the instructions of the pump and packing manufacturers. Allowable leakage is usually between 2 and 60 drops/minute. Add packing rings or, if necessary, replace all the packing.
- ☐ Mechanical Seals. Check for leakage. If leakage exceeds manufacturer specifications, replace the seal.
- ☐ Bearings. Determine bearing condition by: listening for noises that indicate excessive wear, measuring bearing operating temperature, or using a predictive maintenance technique such as vibration analysis or oil analysis. Lubricate bearings in accordance with pump manufacturer instructions. Replace bearings if necessary.
- ☐ Motor/pump Alignment. Determine if motor pump alignment is within service limits of the pump or coupling manufacturer instructions.
- ☐ Motor Condition. Check the integrity of motor winding insulation. Generally, these tests measure insulation resistance at a certain voltage or measure the rate at which an applied voltage decays across the insulation. Also, vibration analysis can indicate certain conditions within the motor windings which can lead to early detection of developing problems.

Motor/Pump Alignment

Since shifting of the pump foundation feet or piping can cause pump/motor misalignment, the alignment should be periodically checked. Alignment is typically measured by reading the total indicated runout (TIR)--also known as full indicator movement (FIM)--of a pump/motor coupling using a dial indicator. Truing the pump/motor alignment typically requires reshimming the liners under the pump feet.

For pumps requiring unusually precise alignments, laser measurement systems offer higher accuracy. The pump's technical manual generally describes the alignment requirements.

Repair Items

Repair items typically include:

Mechanical Seal and Bearing Failure

Although seals and bearings are normal maintenance items, they sometimes fail catastrophically. Worn bearings can create unsatisfactory noise levels or even seize. Occasionally, a bearing or a mechanical seal seizure scores its corresponding shaft sleeve which requires the removal of the pump shaft and the installation of a new sleeve.

Packing Replacement

Packing is a soft, malleable, rope-like material that, when compressed by the packing gland, forms a seal between the pump and the motor shaft. Since packing directly contacts the rotating shaft, it relies on the system fluid for cooling and lubrication. As the packing wears, it must be compressed by tightening the gland nuts. Over time, however, the packing loses its ability to seal and must be replaced.

Packing is typically purchased in rolls and must be cut into sections that are then wrapped around the shaft. Accurately cutting the packing rings is a difficult task, but is essential to ensure proper sealing. Many mechanics facilitate this job by using a piece of pipe or bar stock that is machined to the precise diameter of the motor shaft. By using this mockup shaft, the rings can be cut directly to fit rather than measuring the packing then cutting it. Since packing is typically stretchy, the measure/cut method often leads to poor fit-up.

Mechanical Seal Replacement

In applications that require better sealing than allowed by packing, mechanical seals are typically used. Although mechanical seals are more expensive, they experience less friction and exhibit superior sealing capabilities than packing. Mechanical seals rely on a precisely fit contact between their dynamic surfaces. Mechanical seals can last thousands of hours if they are properly installed, kept clean, and flushed as required. Contaminants can quickly degrade a seal.

Wear Ring Replacement.

Wear rings are fastened to an impeller and/or a casing to act as the wear surface between different impeller stages or between an impeller and a pump casing. Wear rings are sized to establish a certain gap between the high and low pressure sides of an impeller. If this gap grows too large, fluid slips back into the suction side of the pump, creating an efficiency loss. Wear rings with an axial gap may have provisions to compensate for wear. A key indication that wear rings need replacement is when pump performance declines substantially. Unfortunately, wear ring replacement requires pump disassembly.

Motor Replacement

Even properly maintained motors have a finite life. Over time, winding insulation inevitably breaks down. Motors in which the winding temperatures exceed rated values for long periods of time tend to suffer accelerated insulation breakdown. In motor applications below 50 hp, the common repair choice is simply to replace a motor with a new one; however, in larger applications, rewinding an existing motor is often more economically feasible. Although motor rewinds are typically a cost-effective alternative, motors that have been previously rewound can suffer additional efficiency losses during subsequent rewinds.

For motor rewinds, ensure that the repair facility has a proper quality assurance program, since poor quality motor rewinds can compromise motor efficiency. For more information on motor repair, contact the Motor Challenge Clearinghouse at (800) 862-2086.

For motor replacements, high efficiency motors should be considered. High efficiency motors are generally 3 to 8 percent more efficient than standard motors. In high-use applications, this efficiency advantage often provides an attractive payback period. The Energy Policy Act, which went into effect in 1997, set minimum efficiency standards for most general purpose motors from 1 to 200 horsepower. Very efficient motors are available which exceed these requirements.

The MotorMaster+ software program can be a valuable tool in selecting energy efficient motors. The program also allows users to compare motors and estimate energy costs and savings along with life cycle costs. It is available through the Motor Challenge Clearinghouse and can be downloaded from the Motor Challenge website at http://www.motor.doe.gov. Additional information can be found in the *Energy Efficient Motor Selection Handbook* available from the Motor Challenge Clearinghouse.

Impeller Replacement

Impellers often last the life of the pump. However severe cavitation or erosion can degrade an impeller reducing pump performance and efficiency. Impeller replacement is similar to wear ring replacement in that pump disassembly is required.

Predictive Maintenance

In many applications, pump maintenance is reactive. For example, bearing noises indicate the need for lubrication or replacement, excessive packing or seal leakage indicates the need for repair or replacement, and poor pump performance may indicate excessive wear ring degradation.

Fortunately, recent improvements in instrumentation and signal analysis software have increased the availability of vibration testing equipment, thus allowing improved planning of pump/motor maintenance. Vibration analysis equipment is essentially a refined extension of the human ear. By “listening” to the vibrations of a motor or similar piece of machinery, the instrumentation can detect the beginnings of bearing problems, motor winding problems, or other dynamic imbalances. Vibration analysis equipment uses accelerometers to measure the vibration response of machinery during operation and records this data on an amplitude/frequency graph. These vibrations are compared against a baseline set of data, usually taken when the machinery was first operated. By identifying problems before they become larger, repairs can be effectively scheduled and the risk of catastrophic failure can be significantly reduced.

This predictive maintenance effort allows accurate planning of equipment repairs. Two different signatures can be compared to determine the rate at which a problem is developing. This information can be useful, in that a repair may be postponed with an increased level of confidence until a convenient downtime.

Another predictive maintenance technique is oil monitoring and analysis. For pumps with oil lubricated bearings, analyzing oil quality provides another insight into the operating condition of the bearings and seals. An oil analysis can indicate whether a pump has operated at high temperatures, whether system fluid is leaking into the oil, and whether the bearings are nearing the end of their operating life.

Oil analysis can also increase the confidence with which oil changeouts are planned and can eliminate unnecessary oil replacement. This insight can provide substantial cost savings especially if the oil is expensive (for example a synthetic type with sophisticated additives). At approximately $1,000 per analysis, oil monitoring is not economical for all pump applications; however, it can provide some facilities with worthwhile intelligence regarding the condition of their plant equipment.

Another predictive maintenance technique is thermography, or infrared (IR) scanning. IR scans provide early detection of a hot spot and can help avoid an unexpected shutdown. With pump motors, IR scans offer a means of identifying developing problems, for example a hot-running bearing or deteriorating winding insulation.

Centrifugal Pumps

Pumping System Fact Sheet #6
Table of Contents

Basic Principles

The performance of centrifugal pumps is typically described by a graph plotting the pressure generated by the pump (measured in terms of head) over a range of flow rates. Unlike positive displacement pumps which push a certain volume of fluid with each stroke or rotation, centrifugal pumps have variable flow rates even when rotating at a constant speed. This relationship is variable because centrifugal pumps use an impeller, which is basically a rotating wheel, to add energy to a fluid. The high velocity fluid coming off the impeller tip is sent into a diffuser--a chamber that feeds directly into the discharge piping. As the fluid enters the diffuser, it slows and the kinetic energy of the fluid converts to higher pressure. Figure 1 depicts a typical centrifugal pump performance curve.

The amount of fluid that a centrifugal pump moves depends on pump differential pressure. As pump differential pressure increases, flow rate decreases. The rate of this decrease is a function of the pump design. Understanding this relationship is essential to designing, sourcing, and operating a centrifugal pump system.

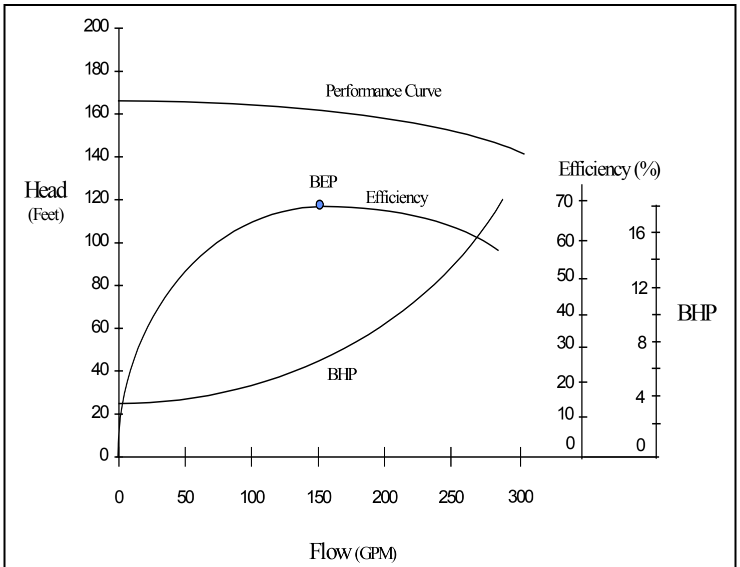


Figure 1 Centrifugal Pump Performance Curves

Also included on a typical pump performance curve are its efficiency and brake horsepower (BHP), both of which are plotted with respect to flow rate. The efficiency of a pump is the ratio of the pump's fluid power to the pump shaft horsepower (which for direct-coupled pump/motor combinations is the motor BHP).

Best Efficiency Point

An important characteristic of the head/flow curve is the best efficiency point (BEP). At the BEP, the pump operates most cost-effectively both in terms of energy efficiency and maintenance considerations.

Operating a pump well away from its BEP may cause accelerated wear of bearings, mechanical seals, and parts. In practice, it is difficult to keep a pump operating consistently at this point because systems usually have changing demands. However, keeping a pump operating within a reasonable range of its BEP lowers overall system operating costs.

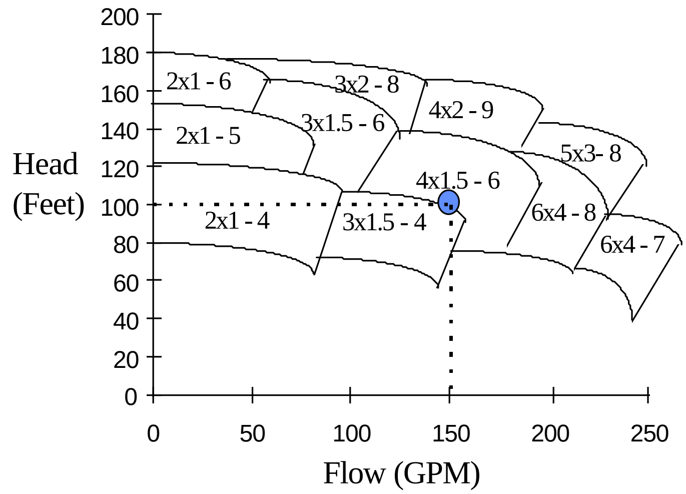


Figure 2 Family of Pump Performance Curves

Family of Pump Curves.

Manufacturers use a coverage chart to describe the performance characteristics of a family of pumps. This type of chart is shown in Figure 2 and is useful in selecting the appropriate pump size for a particular application. The pump designation numbers in Figure 2 refer to the pump inlet size, pump outlet size, and impeller size respectively. There is a significant overlap among these various pump sizes, attributable to the availability of different impeller sizes within a particular pump size.

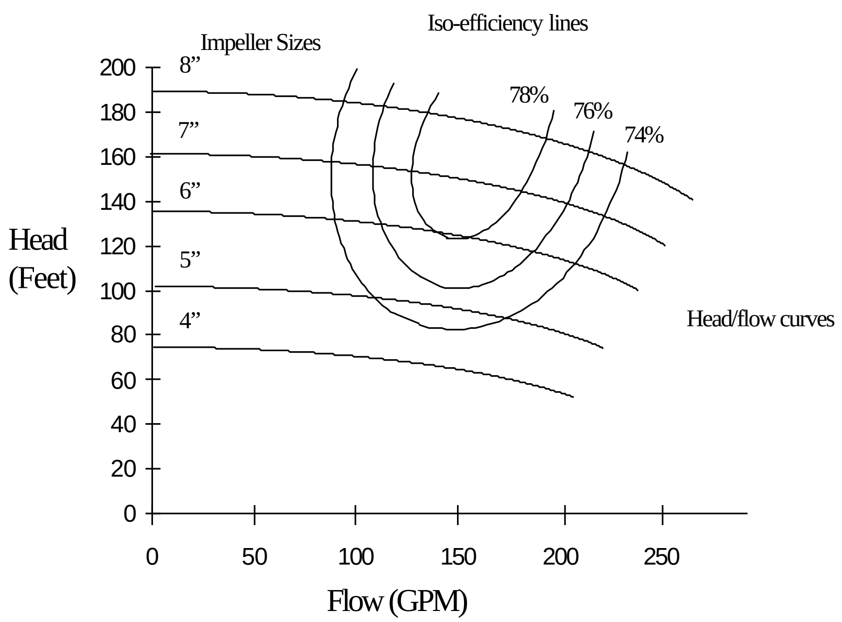


Figure 3 Performance Curves for Different Impeller Sizes

Pump Curves for Multiple Impeller Sizes

Once a pump has been selected as roughly meeting the needs of the system, the specific performance curve for that pump must be evaluated. Often, a pump has several impeller sizes that can be installed with it, and each impeller has a separate performance curve. Figure 3 displays performance curves for each impeller size. Also illustrated are iso-efficiency lines, which indicate how impeller size. Also illustrated are iso-efficiency lines, which indicate how efficient the various impellers are at different flow conditions.

Sizing the impeller and the pump motor is an iterative process which uses the data shown in Figure 3 to determine pump efficiency and performance over its anticipated operating range. For more information, see the Fact Sheet *Impeller Trimming*.

Net Positive Suction Head

In order to avoid cavitation, centrifugal pumps must operate with a certain amount of pressure at the inlet. The pressure is defined as the net positive suction head (NPSH). There are two principal references to NPSH: (1) the available system pressure (NPSHA) at the inlet which is a function of the system and the flow rate, and (2) the required pressure (NPSHR) which is a function of the pump and the flow rate. NPSHR is typically included on pump performance curves. If the NPSHA is sufficiently above the NPSHR, then the pump should not cavitate. A common rule is system design is to ensure NPSHA is 25 percent higher than the NPSHR for all expected flow rates. In practice, however, many oversized pumps operate in regions far to the left of their design points, in which cases, the difference between NPSHA and NPSHR becomes dangerously small.

Pump Speed Selection

Pump speed is often an important consideration in system design. Since many factors affect the appropriate pump speed, pump speed is perhaps best determined by evaluating the effectiveness of similar pumps in other applications. In the absence of such experience, an estimate of pump speed can be made using a dimensionless pump performance parameter known as specific speed. Specific speed can be used in two different references: impeller specific speed and pump suction specific speed. The impeller specific speed (N_s) is typically used to evaluate the performance of different impeller sizes and pump speeds. Suction specific speed (S) is used to evaluate the conditions at the pump suction usually to determine the risk of cavitation.

Specific speed is an index that, in mechanical terms, represents the impeller speed necessary to generate 1 gallon per minute at 1 foot of head. The equation for impeller specific speed is:

$$N_s = \frac{n\sqrt{Q}}{H^{3/4}}$$

Where:
N_s = specific speed
n = pump rotational speed in rpm
Q = flow rate (gpm)
H = total head per stage (feet)

Standard impellers have specific speeds in the range of 500 to 10,000. Pumps with specific speed values between 2,000 and 3,000 usually have the highest efficiency.

Pump suction specific speed (S) is defined by the relationship:

$$S = \frac{n\sqrt{Q}}{NPSHR^{3/4}}$$

Where:
S = specific speed
n = pump rotational speed in rpm
Q = flow rate per impeller (gpm)
NPSHR = The required net positive suction head (feet)

For most applications, a limit of 8,500 suction specific speed should be used to avoid cavitation and extend pump operating life.

Pumps are often driven by induction motors. Typically these motors operate at nominal speeds that are whole number divisors of 3600 rpm, for example, 900 rpm, 1200 rpm, 1800 rpm, and 3600 rpm. A characteristic of this type of motor is that its load torque is directly related to "slip", or the difference between the nominal speed and the actual speed. The slip increases as the load on the motor increases. For example, a pump motor's nameplate data that lists full load speed as 1760 rpm, means that it has a nominal speed of 1800 rpm and slips a little more than 2 percent at rated load.

Example of Pump Selection

The data required to size and source a pump include system flow demands and the system's resistance curve. To determine the system curve, the required data include the system configuration, total pipe length, pipe size, and the number of elbows, tees, fittings and valves. Using this data along with the known fluid properties and the head available from the suction source, a designer can estimate the system's head loss and its NPSHA at the pump suction.

At this point, a designer must review manufacturer's pump data to find pumps capable of meeting system requirements. Unfortunately, this process requires repeated evaluation of many different pump characteristics including BEP, pump speed, NPSHR, and pump type. Using the expected system operating range, a designer must evaluate the family of performance curves, similar to Figure 2, for each pump manufacturer to identify pumps that meet service needs.

The next step is to evaluate the performance curves of each of the above selected pumps. Each pump usually has a range of performance curves for each impeller size offered with that pump. In addition to different stock impeller sizes, an impeller can be trimmed to further "fine tune" a pump's performance (see the *Impeller Trimming* Fact Sheet).

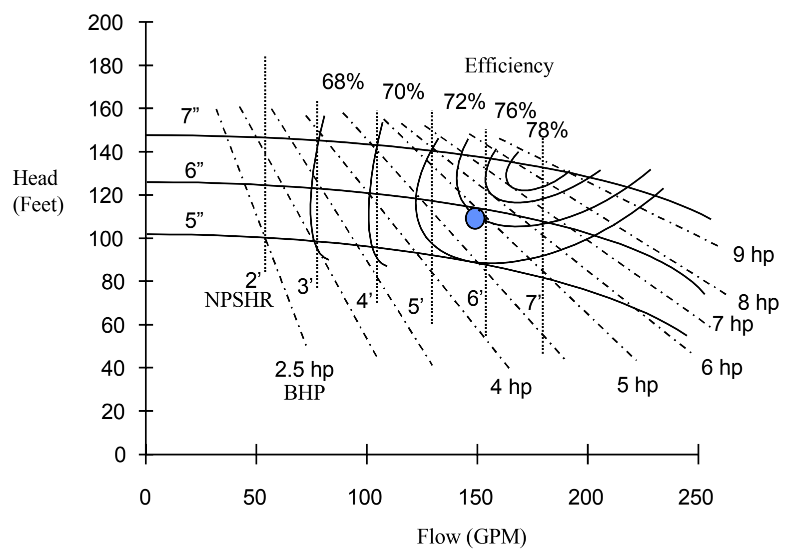


Figure 4 Performance Curves for the 4x1.5-6 Pump

In Figure 4, the 4x1.5 - 6 pump is used as an example. The design point is just below the curve for the 6-inch impeller. For this particular pump size, at these operating conditions, pump efficiency is 74 percent and the 5-hp motor appears strong enough to meet service requirements. The pump's BEP is just slightly to the right of the design point and the NPSHR is 6 feet. If the

NPSHA is more than 9 feet, or at least 25 percent higher than the NPSHR, the 4x1.5 - 6 pump looks suitable.

Pump Manufacturer Software

The complexity of pump selection has motivated most pump manufacturers to develop software that, using specific system requirements, identifies pumps capable of meeting an end-user's service needs.

Prospective customers enter known system characteristics such as head, flow, pipe size, NPSHA and key fluid properties and the software generates a list of pumps suitable for the application.

The software contains performance data on each of the manufacturer's pumps for further analysis. Pump constraints, such as required pump speed, can also be used to further refine the list of candidate pumps. Although system performance concerns such as head/flow curve sensitivity and multiple pump configurations still require sound engineering judgment, the use of pump manufacturer software can simplify the pump selection process.

Positive Displacement Pump Applications

Pumping System Fact Sheet #7
Table of Contents

Basic Principle

The term positive displacement refers to the manner in which these pumps pressurize and move fluid. Positive displacement pumps squeeze fluid by decreasing the volume that contains it. For example, one type of positive displacement pump is a piston pump: every stroke pushes along a certain amount of fluid. An example of a rotary displacement pump is a screw pump which uses two parallel, overlapping screws to push along a certain volume with each revolution.

Applications

Although positive displacement pumps have higher maintenance requirements, there are services for which positive displacement pumps are inherently better suited. Among these applications are:

- ***High Pressure/Low Flow Applications.***

  Positive displacement pumps are usually more effective in generating high pressures in low flow applications. Although centrifugal pumps can be designed to generate high pressures--usually through the use of multiple stages--these special pumps tend to be comparatively expensive.

- ***High Fluid Viscosity Applications***

  Positive displacement pumps are more effective than centrifugal pumps in pumping viscous fluids. By directly pressurizing the fluids, positive displacement pumps suffer less energy loss to the high shear stresses which are inherent to viscous fluids.

- ***Accurately Controlled Flow Applications***

  Since each stroke or revolution generates a certain amount of flow, positive displacement pumps are typically used in precise flow control applications. By controlling the number of pump cycles, positive displacement pumps are well-suited for metered flow applications.

In addition, many positive displacement pumps have unique characteristics that make them attractive. For example, positive displacement pumps are usually self-priming and can operate with entrained gases in the suction line. This feature allows positive displacement pumps to be located above the fluid level which can simplify the layout of many systems. Centrifugal pumps often require special system equipment to remove gases and to prime the impeller. Although some centrifugal pumps are designed to be self-priming, these pumps are expensive, less reliable, less efficient, and still require gas removal.

Certain positive displacement pumps such as diaphragm and peristaltic types do not require seals and, therefore, do not leak. In systems that handle corrosive or hazardous fluids, eliminating the need for seal maintenance can yield substantial cost savings.

Special Considerations

Positive displacement pumps are usually installed with pressure relief valves. In fact, many of these pumps have relief valves built internal to the pump. This protection is needed because the pumps push fluid into the discharge line irrespective of backpressure; consequently, if the system flow gets completely obstructed downstream of the pump, fluid pressure builds until the motor torque reaches an overload condition or until the piping or equipment ruptures. Although relief valves are designed to protect against such damage, they require periodic testing and maintenance. Failure of the relief valve to operate properly can result in expensive system damage.

Positive displacement pumps also typically have pulsating flow characteristics. In some systems, these pulsations can create vibration problems, especially if the pulse rate has a harmonic component that coincides with the natural frequency of any piping or structure. Flow-induced piping vibrations create cyclic loading on piping welds and piping supports, and can also accelerate the loosening of mechanical joints. These vibrations can be dampened using accumulators to absorb some of the vibrational energy.

Another consideration with positive displacement pumps is the need for spare parts storage. The relatively high number of moving parts associated with many positive displacement pumps requires some facilities to maintain a large spare parts inventory. For example, many reciprocating pumps contain internal valves with mating surfaces that are susceptible to wear and require periodic replacement. Although these parts can be obtained from a manufacturer or part supplier, plants often prefer to keep common replacement parts on-hand to minimize downtime. Consequently, the use of pumps with large numbers

Multiple Pump Arrangements

Pumping System Fact Sheet #8
Table of Contents

Basic Principles

An alternative to using one pump to serve the requirements of a system is to use several smaller pumps in combination. Wide variations in system demand preclude a single pump from consistently operating close to its best efficiency point (BEP). Operating a pump away from its BEP can result in higher operating and maintenance costs. In some systems, especially those with high static head requirements, by energizing or de-energizing multiple pumps to meet demand changes, each pump can operate at a more efficiently, improving overall system efficiency. However, this efficiency advantage depends on the pump curves, the system curve, and the demand change that is being met.

Among the advantages of multiple pump arrangements are flexibility, redundancy, and the ability to efficiently meet changing flow needs in systems with high static head components. In systems, with high friction components, alternatives such as adjustable speed motors tend to provide a more efficient solution to variable demand requirements.

Multiple pumps are usually parallel combinations of the same pump model. Placing an additional pump on-line adds flow to the system and shifts the operating point to the right along the system curve (see Figure 1). The reason each pump is the same model is to provide balanced load sharing during periods when all the pumps are operating. Using different size pumps risks a condition in which the largest pump dominates the system forcing other pumps to operate below their minimum flow ratings. If different size pumps must be configured in parallel, their performance curves should be carefully reviewed to ensure none of the pumps operates below its minimum flow requirement.

Best Efficiency Point (BEP)

Every centrifugal pump has a best efficiency point (BEP); a point at which its operating efficiency is highest and its radial bearing loads are lowest. A pump's BEP is a function of its inlet configuration, impeller design, casing design, and pump speed.

Most centrifugal pumps are equipped with roller or ball bearings. Since the operating life of these bearing types is an inverse function of the cube of the load, selecting a pump with a BEP that is close to the system's normal operating range significantly extends the interval between bearing replacement.

Advantages

There are many advantages to using combinations of smaller pumps in place of a single large one.

Operating Flexibility

As shown in Figure 1, the use of several pumps in parallel broadens the range of flow that can be delivered to the system. Additionally, by energizing and de-energizing pumps, the operating point of each pump can be kept more closely near its BEP. Caution should be used in operating parallel pumps to ensure that the minimum flow requirement is not violated for any pump.

Redundancy

Failure of one unit does not force a system shutdown. With a multiple pump arrangement, one pump can be repaired while the others serve the system.

Maintenance

Multiple pump configurations allow each pump to be operated close to its BEP, which lowers bearing wear and permits the pumps to run more smoothly. Other benefits include less reliance on energy-dissipating flow control options such as bypass lines and throttle valves. The use of a single, large pump during low flow demand conditions forces the excess flow to be throttled or bypassed. Throttling the flow wears the throttle valves and creates energy losses. Similarly, bypassing the flow is highly inefficient, since all the energy used to push the excess flow through the bypass lines is wasted.

Excess flow creates maintenance problems in terms of piping vibrations which fatigue welds in the piping and piping supports and loosen flanged joints.

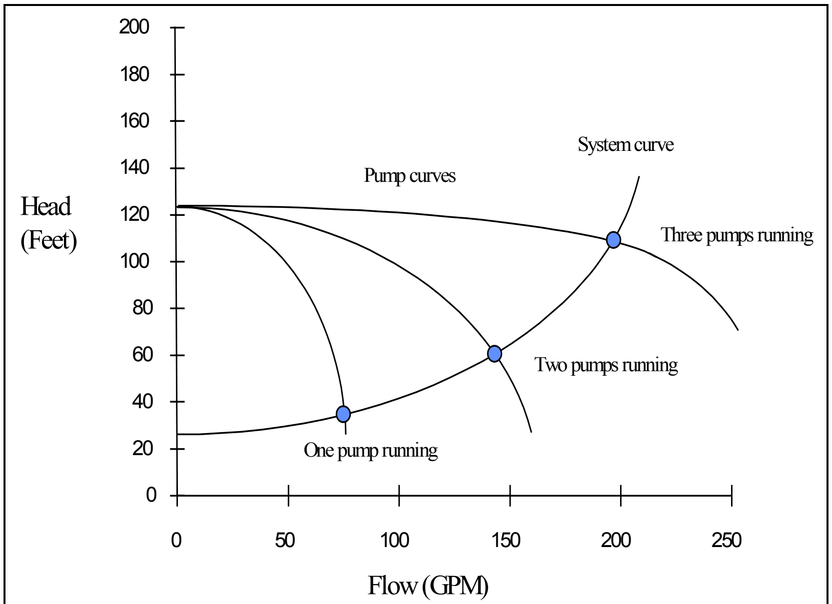


Figure1 Multiple Pump Operation

Efficiency

A potential advantage from multiple pumps is a higher overall efficiency level since each pump can operate close to its BEP. By energizing or de-energizing pumps as necessary to meet changes in system demand, each pump can operate over a smaller region of its performance curve, ideally around the BEP. Alternatively, a single pump would have to operate over a larger range forcing it to operate further away from the BEP.

Additionally, at a given head and flow, high speed pumps tend to be more efficient than slow speed pumps. (Exception: pumps with specific speed values greater than 3,000 tend to be less efficient at higher speeds; however, this is not typical of most pumps). Since smaller pumps require smaller motors, the use of multiple high speed pumps can provide an efficiency advantage over a single, slow speed pump. However, this efficiency advantage should be balanced against the tendency for higher speed machines to require more maintenance.

Other Options

Other system designs that can be used to handle widely varying operating conditions include pony pumps, multiple speed pumps, and variable frequency drives. For more information on pony pumps see the Fact Sheet titled *Pony Pumps*. Information on variable frequency drives can be found in the Fact Sheet titled *Variable Frequency Drives*.

Multi-speed pumps are used in similar ways as multiple pump configurations in that the fluid power generated can be matched to the demands of the system. Shifting a pump to higher or lower speeds moves the entire performance curve up or down respectively as shown in Figure 2.

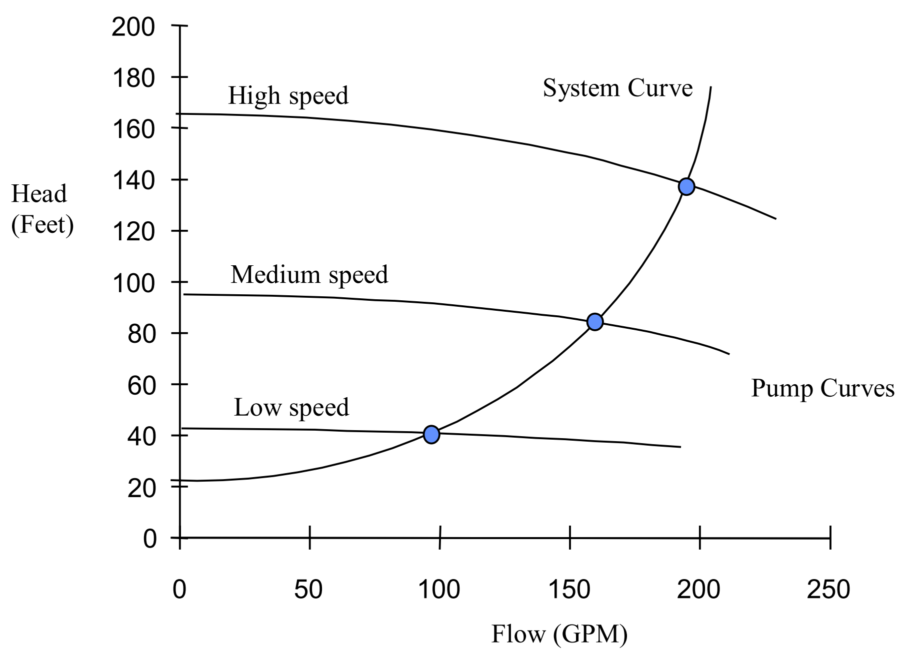


Figure 2 Multiple Speed Pump Performance Curves

Although at any given operating point, multi-speed pumps tend to perform less efficiently than single speed pumps, their ability to operate over a wide range of conditions offers a key advantage. Multiple speed pumps also offer space savings. Their compact operating package avoids the additional piping and valves required for parallel pumps.

Pony Pumps

Pumping System Fact Sheet #9
Table of Contents

Basic Principles

Many pump applications have a diverse range of flow needs. Often, there is a large difference between the flow required during normal system operation and that required during peak load conditions. For example, rainwater collection and some cooling system applications typically require a relatively low flow rate. Occasionally, however, a heavy storm or exceptionally large heat load due to a sudden increase in production demand creates a need for high pumping capacity.

If the pumps are sized to handle peak flow, or worst-case conditions, they may operate at substantially inefficient levels for long periods before operating briefly at their design points during periods of high demand. These oversized pumps tend to wastefully consume energy and require frequent maintenance because they operate far away from their best efficiency points.

Similarly, in sewage treatment plants the normal operating demands on pumps may be relatively low. During storms, however, the amount of fluid which must be drained from the various holding ponds or tanks increases dramatically. Obviously, the pump(s) that maintain holding pond levels must be capable of handling storm conditions.

To avoid the high friction losses and maintenance problems that accompany continuous operation or frequent starts of oversized pumps, a plant can install smaller (pony) pumps to handle normal operating conditions. The larger pumps would then only be used to handle the occasionally severe load conditions, providing considerable cost savings.

When to Consider Pony Pumps

Indicators of a need for a smaller pump to handle normal operating conditions include:

- Intermittent pump operation, and
- High flow noise, cavitation, and piping vibrations which disappear during heavy demand periods. (If these conditions persist, then the primary pump may need to be downsized).

Costs of Intermittent Pump Operation

Intermittent pump operation is caused by an imbalanced set of system flows. The pump's high flow rate drains the tank or reservoir to the low level switches which de-energize the pump. Once the fluid level in the tank rises to the high level switch, the pump re- energizes and drains the tank again (see Figure 1).

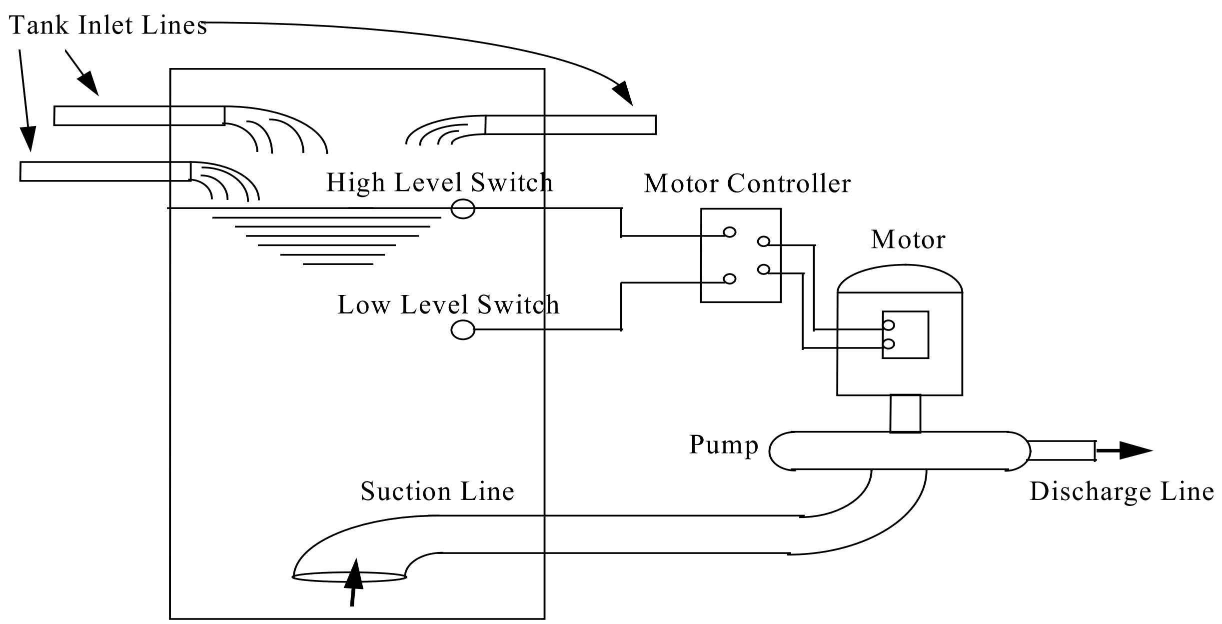


Figure 1 Typical Tank Level Control System

Repeatedly energizing and de-energizing a pump wears the motor controllers and dynamic surfaces in the pump/motor assembly and can lead to unreliable pump operation. This problem is especially severe for large pumps due to their high starting currents. Each repeated closing and opening of high voltage contacts also creates a danger of sparking that can damage the contact surfaces. In addition, discontinuous loading of the transformers and switchgear often shortens their operating lives. (Some pump/motor assemblies are specially designed to handle repeated starting and stopping. For such applications, this more expensive type of equipment should be specified.)

Many pumps do not respond well to startups and shutdowns. The mechanical seals used in many pumps rely on a lubricating film of the system fluid. This film requires a revolution or two to develop and, over time, repeated startups accelerate seal wear. Similarly, bearings that are subjected to cyclical loading tend to have shorter operating lives than those in constant-use applications.

Costs of High Flow Velocity

An additional penalty for using an oversized pump is the added friction losses which occur during pump operation. Higher flow rates create higher flow velocities which, in turn, leads to higher friction loss. The relationship between velocity and friction loss is provided by the Darcy-Weisbach equation.

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

Where:
h_f = head loss;
f = pipe friction coefficient;
V = fluid velocity;
g = gravitational constant;
D = inner diameter of the pipe;
L = length of pipe

As shown by the V^2 term, the pressure loss through a pipe is proportional to the square of the fluid velocity. Consequently, given the same size pipe, a flow rate which is two times higher endures four times more friction loss. This means that it costs much more to pump a gallon of fluid at a higher-than-necessary flow rate.

Recovering the Costs of Installing a Smaller Pump

The installation of a smaller pump to run parallel to an existing one can provide substantial savings in terms of energy and maintenance costs. Using a simple economic analysis, an end-user can compare the existing power consumption and maintenance intervals against the capital cost and the projected savings of operating a smaller, more efficient pump.

Alternatives to a pony pump include other energy saving efforts such as reducing the impeller size, substituting the existing pump/motor assembly with a smaller one, and installing an adjustable speed drive (ASD) on the pump motor. Depending on the particular requirements of the application, impeller adjustments and the smaller pump/motor assembly could compromise the capacity of the existing pump during worst-case situations. Although ASDs in general allow the pump to run at lower capacity, variable frequency drives (VFDs) are more suitable for varying demand rather than continuously low demand.

VFDs themselves introduce efficiency losses and, if normal operation is far below the full load rating of the motor for long operating periods, these losses can incur a discouraging cost. A VFD can also introduce harmonics in the motor windings which increases winding temperature. Increased motor winding temperature over extended periods accelerates insulation breakdown. For more information on VFDs, see the Fact Sheet titled *Controlling Pumps with Variable Frequency Drives*.

A practical example of the successful use of pony pumps is found in a Motor Challenge Showcase Demonstration project undertaken by the City of Milford, Connecticut. By adding a pony pump to the city.s Welches Point Sewage Lift station, Milford was able to realize substantial energy savings and reduced maintenance costs. This project is described in the case study, *Saving Energy at a Sewage Lift Station Through Pump System Modifications* (for more information, call the Motor Challenge Clearinghouse at 800-862-2086).

Impeller Trimming

Pumping Systems Fact Sheet #10
Table of Contents

Basic Principles

Impeller trimming refers to the process of machining the diameter of an impeller to reduce the energy added to the system fluid. Impeller trimming offers a useful correction to pumps that, through overly conservative design practices or changes in system loads are oversized for their application.

Trimming an impeller provides a level of correction below buying a smaller impeller from the pump manufacturer. In many cases, the next smaller size impeller is too small for the pump load. In some cases, smaller impellers may not be available for the pump size in question and impeller trimming is the only practical alternative short of replacing the entire pump/motor assembly.

When to Consider Impeller Trimming

End-users should consider trimming an impeller when:

- Many of the systems bypass valves are open, indicating excess flow available to the system equipment;
- High noise or vibration levels exist indicating excessive flow; and/or
- A pump is operating far from its design point.

Why Impeller Trimming Works

Impeller trimming reduces tip speed, which in turn directly lowers the amount of energy imparted to the system fluid and lowers both the flow and pressure generated by the pump (see Figure 1). The Affinity Laws, which describe centrifugal pump performance, provide a theoretical relationship between impeller size and pump output (assuming constant pump speed):

$$Q_2 = \frac{D_2}{D_1} Q_1$$

$$H_2 = \left[\frac{D_2}{D_1}\right]^2 H_1$$

$$BHP_2 = \left[\frac{D_2}{D_1}\right]^3 BHP_1$$

Where:
Q = flow and H = head
BHP = brake horsepower of the pump motor
Subscript 1 = original pump
Subscript 2 = pump after impeller trimming
D = Diameter

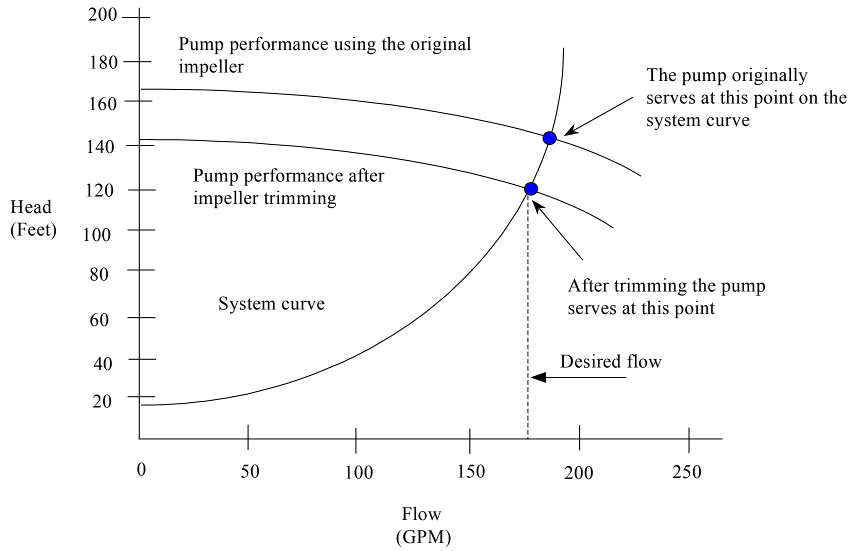


Figure 1 The Effect of Impeller Trimming on Pump Performance

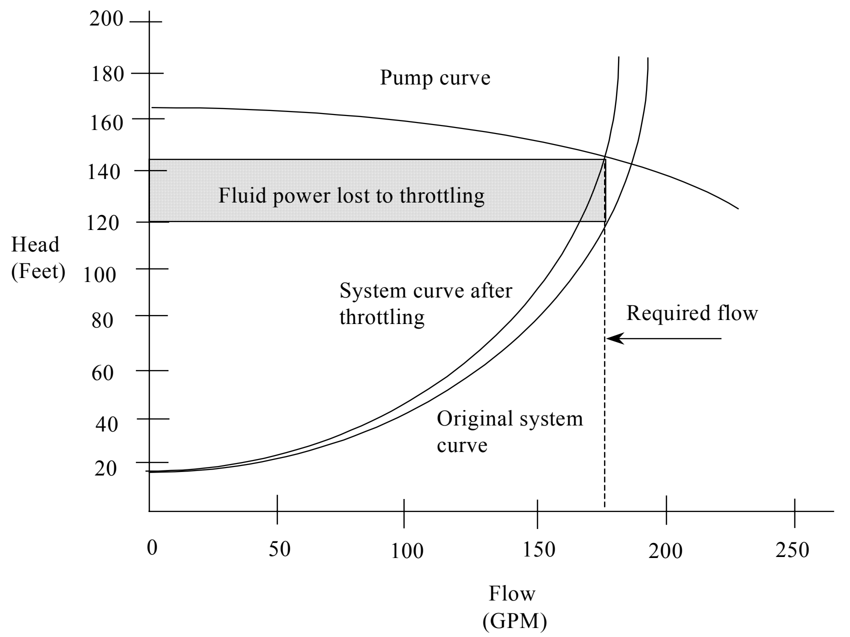


Figure 2 Fluid Power Lost Across a Throttle Value

In practice, these relationships are not strictly accurate due to flow non-linearities; however, the fundamental effect of impeller trimming on flow, head, and brake horsepower holds. For example, a 2 percent reduction in impeller diameter creates about a 2 percent reduction in flow, a 4 percent reduction in head, and an 8 percent reduction in power.

Benefits of Impeller Trimming

A principal benefit of reducing impeller size is decreasing operating and maintenance costs. Less fluid energy is wasted in the bypass lines and across throttle valves, or dissipated as noise and vibrations through the system. Energy savings are roughly proportional to the cube of the diameter reduction and are illustrated in figure 2. (Refer to the fluid power equation discussed in the *Introduction to Pumping Systems*):

$$\text{Fluid power} = \frac{H * Q}{3960} * \text{s.g.}$$

The actual energy saving will be somewhat higher than shown by the fluid energy savings due to the avoided energy lost to inefficiencies in the pump and motor.

In addition to energy savings, impeller trimming also reduces wear on system piping, valves, and piping supports. Flow-induced piping vibrations tend to fatigue pipe welds and mechanical joints. Over time, welds crack and joints loosen, causing leaks and forcing downtime to make necessary repairs.

Furthermore, excessive fluid energy is not a normal design consideration. Pipe supports are typically spaced and sized to withstand static loads from the weight of the pipe and the fluid, pressure loads from the internal system pressure, and –in thermally dynamic applications - expansion due to temperature changes. The vibrations created by excessive fluid energy therefore provide a load that the system is not designed to handle, leading to leaks, downtime, and additional maintenance.

A practical example describing how impeller trimming lowers maintenance requirements is found in the Motor Challenge Showcase Demonstration Case Study, Optimizing Pump systems at a Coal Slurry Preparation Plant, (for more information, call the Motor Challenge Clearinghouse at 800-862-2086).

Limitations

Trimming an impeller changes its operating efficiency, and the non-linearities of the Affinity Laws with respect to impeller machining complicate the prediction of pump performance. Consequently, impeller diameters are rarely reduced below 70 percent of their original size.

In addition, for some pumps, impeller trimming increases the pump's required net positive suction head. Recall that in order to avoid cavitation, a centrifugal pump mist operate with a certain amount of pressure at its inlet. This pressure is defined as the required net positive suction head (NPSHR). To reduce the risk of cavitation, the effect of impeller trimming on NPSHR should be evaluated using manufacturer-provided data over the full range of operating conditions. For further description of NPSHR, see Fact Sheet #6 on *Centrifugal Pumps*.

Controlling Pumps with Variable Frequency Drives

Pumping System Fact Sheet #11
Table of Contents

Basic Principles

Centrifugal pumps often serve over a wide range of operating conditions. For example, many cooling systems see variable loads due to changes in ambient conditions, occupancy, and production demands. To accommodate demand changes, flow is controlled by three principal methods: bypass lines, throttle valves, or pump speed adjustments.

Bypass Lines

Bypass lines provide accurate flow control while avoiding the danger of deadheading a pump -- the condition in which a pump's flow is completely choked by closed downstream valves. Unfortunately, bypassing flow is usually the least energy-efficient flow control option.

Throttle Valves

Throttle valves provide flow control in two ways: by increasing upstream backpressure, which reduces pump flow, and by directly dissipating fluid energy. By increasing backpressure on a pump, throttle valves shift a pump's operating point to the left along its performance curve. Pumps that operate far away from their best efficiency points (BEPs) suffer increased operating and maintenance costs.

Pump Speed Adjustments

In contrast, pump speed adjustments provide the most efficient means of controlling pump flow. By reducing pump speed, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. There are two primary methods of reducing pump speed: multiple-speed pump motors and adjustable speed drives (ASDs). Although both directly control pump output, multiple-speed motors and ASDs serve entirely separate applications.

Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single speed motors. Multiple speed motors also lack subtle speed changing capabilities within discrete speeds.

ASDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. ASDs control pump speeds using several different types of mechanical and electrical systems. Mechanical ASDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical ASDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed. VFDs are by far the most popular type of ASD.

Pump speed adjustment is not appropriate for all systems, however. In applications with high static head, slowing a pump risks inducing vibrations and creating performance problems that are similar to those found when a pump operates against its shutoff head. For systems in which the static head represents a large portion of the total head, caution should be used in deciding whether to use ASD.s. Operators should review the performance of ASDs in similar applications and consult ASD manufacturers to avoid the damage that can result when a pump operates too slowly against high static head conditions.

Pump Operating Efficiency Improvements

For many systems, VFDs offer a means to improve pump operating efficiency despite changes in operating conditions. The effect of slowing pump speed on pump operation is illustrated by the three curves in Figure 1. When a VFD slows a pump, its head/flow and brake horsepower (BHP) curves drop down and to the left and its efficiency curve shifts to the left. This efficiency response provides an essential cost advantage; by keeping the operating efficiency as high as possible across variations in the system's flow demand, the energy and maintenance costs of the pump can be significantly reduced.

System Operating Efficiency Improvements

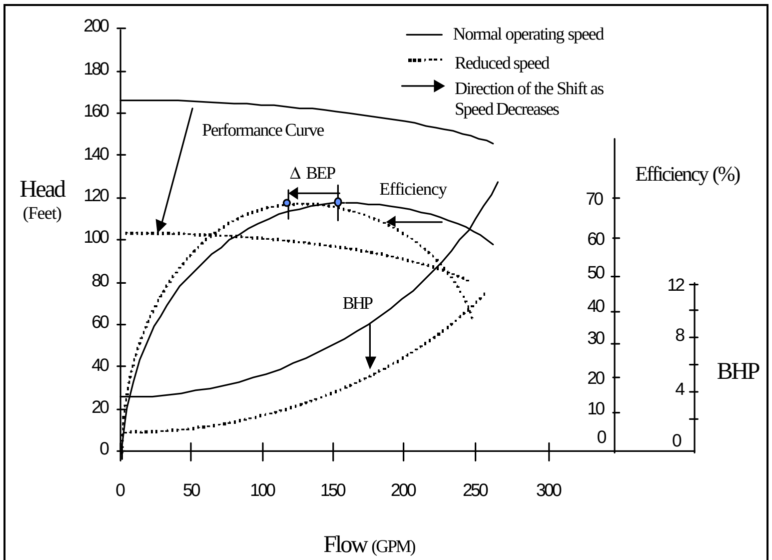


Figure 1 Effect of Reducing Speed on Pump Operating Characteristics

VFDs may offer operating cost reductions by allowing higher pump operating efficiency, but the principal savings derive from the reduction in frictional or bypass flow losses.

Using a system perspective to identify areas in which fluid energy is dissipated in non-useful work often reveals opportunities for operating cost reductions. For example, in many systems, increasing flow through bypass lines does not noticeably impact the backpressure on a pump. Consequently, in these applications pump efficiency does not necessarily decline during periods of low flow demand. By analyzing the entire system, however, the energy lost in pushing fluid through bypass lines and across throttle valves can be identified. Figure 2 describes the energy losses attributable to bypass valve operation, while Figure 3 depicts the energy losses attributed due to throttling. VFDs can decrease energy losses by lowering overall system flow or head. By slowing the pump and lessening the amount of fluid energy imparted to the system when it is not needed, VFDs offer substantial savings with respect to the cost per gallon of liquid pumped.

Another system benefit of VFDs is a soft start capability. During startup, most motors experience in-rush currents that are 5 - 6 times higher than normal operating currents. This high current fades when the motor spins up to normal speed. VFDs allow the motor to be started with a lower startup current (usually only about 1.5 times the normal operating current). This reduces wear on the motor and its controller.

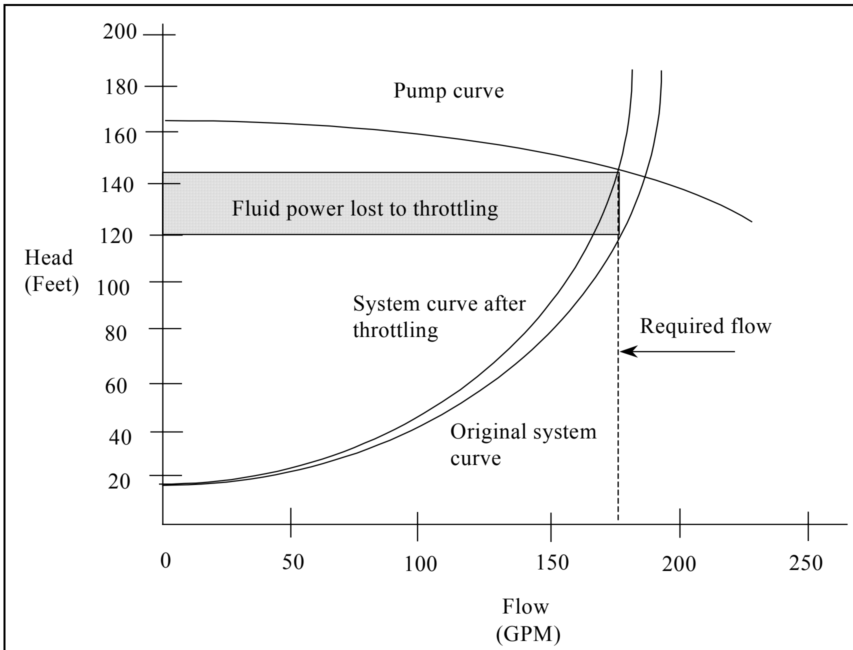


Figure 2 Fluid Power Lost Across a Throttle Valve

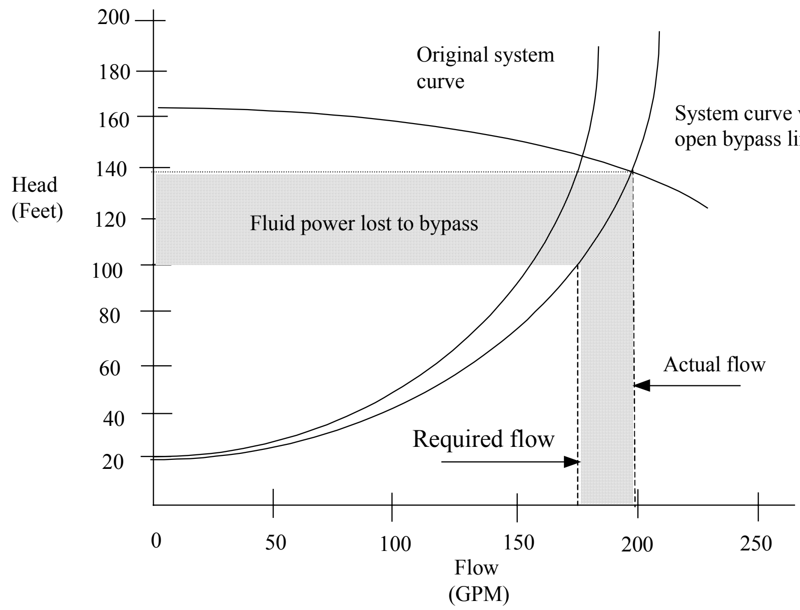


Figure 3 Power Lost Through a Bypass Line

Maintenance Requirements

As added system equipment, VFDs themselves require maintenance and repairs. However, in many applications, VFDs offer decreased maintenance requirements on the pump itself and system piping and components. The principal factors behind these maintenance savings are the reduced load on the pump and the lower static and dynamic fluid forces imparted to the system.

By decreasing a pump's operating speed, a VFD often shifts the BEP to the left of the BEP corresponding to the pump's normal operating speed. In these cases, since the bearing loads on a pump are lowest when the pump is operating at its BEP, this shift of the BEP during periods of low flow allows the pump to operate with lower bearing loads and less shaft deflection. Most pump bearings are roller- or ball-type which have a design operating life that is a function of the cube of the load. Consequently, a VFD can extend the interval between bearing maintenance.

Another benefit of VFDs is reduced stress on pipes and piping supports. During periods in which the system flow far exceeds equipment demands, excess fluid energy is dissipated in the form of noise and vibration. Vibrations promote the loosening of mechanical joints and the cracking of welds in pipes and pipe hangers. By reducing fluid energy, VFDs lessen system wear. For further information on indications of excessive system flow and other means of correcting it, see the Fact Sheet titled *Indications of Oversized Pumps*.

Limitations of VFDs

Although VFDs offer a number of benefits in terms of lower operating and maintenance costs, they are not appropriate for all applications. As a pump's speed decreases, it generates less pressure. In high static head applications, the use of VFDs can slow a pump down such that it operates at or near shut-off head conditions. Under these conditions, the pump experiences the same harsh treatment that manufacturer attempts to guard against when it sets the minimum flow rate (which usually corresponds to the pumps rated speed). These consequences include increased shaft deflection, high vibration levels, and high bearing loads. Under these conditions, although the motor consumes less energy, the pump may be damaged.

Power quality can also be a concern. VFDs operate by rectifying the alternating current (ac) line power into a direct current (dc) signal, then inverting and regulating this signal into ac power that is sent to the motor. Often, the inverter creates harmonics in the power supplied to the motor. These harmonics can cause motor windings to operate at higher temperatures which accelerates insulation degradation. To account for the added winding heat, motors must typically be derated 5 - 10 percent when used with VFDs. A classification of motors known as “inverter-duty” has been developed to improve the matching of VFDs to motors.

Additionally, in some electrical systems, these harmonics can be picked up by other electrical lines that have common connections with the VFD. Systems which are sensitive to minor power supply disturbances should be served separately from the VFD power supply.

In some applications, VFDs can contribute to reduced bearing life. The interaction between the three phases of the power supply from a VFD inverter can sometimes induce a small voltage across the motor bearings. As a result, these bearings can suffer pitting and accelerated wear. VFD manufacturers are familiar with this problem and there are several methods that are used to correct it, including insulating certain bearings, grounding the shaft, and conditioning the power supply.

Finally, in some applications, anticipated energy savings are not realized due to incomplete consideration of all the losses associated with VFD installation. The VFDs themselves are approximately 95 percent efficient. In addition, the quality of electric power supplied to the motor decreases both its efficiency and power rating. Although VFDs are an attractive option in many applications, all of these considerations should be incorporated into the feasibility study.

Pumping System Economics

Pumping System Fact Sheet #12
Table of Contents

Pumping systems are often critical to plant operation. In fact, about 27 percent of all energy consumed by motor driven equipment in manufacturing facilities is for pump operation. In many industrial applications, such as power and petrochemical plants, pumps directly support production processes and run as often as or longer than any other equipment at the facility. With such high run times, the energy consumed by many pumping systems often results in substantial annual costs.

In spite of this, many facilities have no idea how much pump operation costs on an annual basis, or how much money they could save by improving the performance of pumping systems.

The life cycle costs of pumps are difficult to summarize because, even among pumps of the same size, the initial costs vary widely. Other costs, such as maintenance and disposal or decommissioning may be difficult to quantify. In response, the Hydraulic Institute[1] recently formed a committee to develop educational material to encourage greater consideration of life cycle cost in pumping system specification and operation.

Other efforts, such as the Department of Energy's Motor Challenge Program, have developed products and information resources that can help end-users reduce pumping system operating costs. Specifically, MotorMaster+ is a software product that supports motor management decisions and can be used to perform economic feasibility calculations on motor replacements and upgrades. For more information on MotorMaster+ and other products, see the *Resources and Tools* section.

Additionally, Appendix C, developed by Oak Ridge National Laboratory and titled *Prescreening Motor Systems for Potential Energy Savings*, provides an assessment tool to determine how well a pump is matched to its system. By providing guidelines, a checklist, and data collection sheets, this guide can assist system operators in identifying and prioritizing energy reduction opportunities in pumping systems.

[1] A manufacturers trade association, see the Directory of Contacts.

Operating costs of pumping systems include electricity and maintenance costs. Of these two components, electricity costs are relatively easy to determine with simple measurements. However, maintenance costs are highly dependent on service conditions and need to be evaluated case by case. A particularly useful method of estimating these costs is to review the maintenance histories of similar equipment in similar applications.

Load Factor

Pump economic analyses are largely impacted by the amount of time and the percentage of its full capacity at which a pump operates. To account for the fact that the pump usually does not operate at rated full load all the time, an estimate of its average load factor can be made. The term load factor refers to the average percentage of full load that the pump operates.

Unfortunately, unless operators maintain comprehensive records or are highly familiar with pump operating data, the average load factor may be difficult to determine.

Calculating Electricity Costs

Electricity costs can be determined by several methods including:

- direct measurement of motor current,
- the use of motor nameplate data, and
- the use of performance curve data.

Simple Calculation

With any of these methods, the data's usefulness is limited by how representative it is of the average system operating conditions. In systems with widely varying operating conditions, simply taking data once will probably not provide a true indication of pumping system energy consumption.

Nameplate Data

A quick way to determine energy costs is to use the pump motor nameplate data. In many applications, the pump/motor is oversized which means the motor operates below its full load nameplate indication. By estimating the load factor and the power factor, the pump's annual operating costs can be calculated.

Simple Calculation

Annual Electricity Costs =
(Motor full-load brake horsepower) x (0.746 kW/hp) x (1/0.95) x (Annual Hours of Operation) x (Electricity Cost in $/kWh) X Load Factor

Assumptions:
- Cost of electricity = $0.05/kWh
- Load Factor = 65 %
- Motor efficiency = 95%

For example:
- Motor full-load bhp = 100 hp
- Annual hours of operation = 8,760 hours (3-shift, continuous operation)

Annual electricity costs =
(100 hp) x (0.746 kW/hp) x (1/0.95) x (8,760 hours) x ($0.05/kWh) X .65
= $22,356

Other necessary data include the annual hours of operation (hrs/year) and the unit cost of electricity ($/kWh). Annual electricity costs can be calculated by inserting this information into the following equation in the *Simple Calculation* text box.

This equation assumes the electric motor driving the pump is 95% efficient (the 0.95 in the 1/0.95 factor) -- a reasonable estimate for a pump motor larger than 50 hp. Newer motors may have even higher efficiencies, as a result of the Energy Policy Act which has been in effect since late 1997. If the pump uses an older motor that has been rewound several times, or has a smaller motor, then a motor efficiency of 80% (or the motor nameplate efficiency rating) should be used. The motors used on most centrifugal pumps have a 1.15 continuous service factor. This means that a motor with a nominal nameplate rating of 100 bhp may, in fact, be operated continuously up to 115 bhp, although motor efficiency drops slightly above the rated load. Using nameplate data to calculate energy costs on motors that operate above rated load will understate the actual costs.

Direct Measurement

A more accurate way to determine electricity consumption requires taking electrical measurements of both full-load amps and volts. This method requires reading full-load amps and volts, then converts them to full-load kW, or directly reading full-load kW with a wattmeter. The kW value is then multiplied by hours of operation and electricity costs. A calculation is shown in the *Direct Measurement* text box.

Measuring Amps and Volts

Using a clamp type ammeter, the current on each of the three power cables running to the motor (most industrial motors are three phase) can be measured. Sometimes the motor controller is a convenient point to take these readings, while at other sites, the connection box on the motor itself is more accessible. Line voltage is usually measured at the motor controller and should be measured at the same time as the current reading. (In some facilities, line voltage droops with increased power usage).

Using a Wattmeter

Wattmeters, in general, are more difficult to use since they require two simultaneous inputs (voltage and current) and many motor installations do not offer convenient access to both. However, if the use of a wattmeter is practical, then it would provide a more accurate indication of actual power consumption. Wattmeters provide a direct

Direct Measurement Calculation

Assumptions:
- 3 phase motor
- 0.85 power factor
- 0.65 load factor
- 0.05 $/kWh unit electricity cost
- Cost of electricity = $0.05/kWh

Case I. Separately using a voltmeter and an ammeter.
Annual Electricity Costs =
((Full-load amps)x(volts)x(1.732)x(power factor))/1000)x
(Annual Hours of Operation) x (Electricity Cost in $/kWh) x (0.65 Load Factor)

For example:
- Full-load amps = 115 amps
- Voltage=460 volts
- Annual hours of operation = 8,760 hours (3-shift, continuous operation)

Annual electricity costs =
((115 amps)x(460 volts)x(1.732)x(0.85)/1000)x
(8,760 hours)x($0.05/kWh) X .65
= $22,172

Case II. Use of a wattmeter.
Annual Electricity Costs =
Wattmeter reading (using a 3 phase setting) x
(Annual Hours of Operation) x (Electricity Cost in $/kWh)
x (0.65 Load Factor)

For example:
Wattmeter reading = 77.88 kW
Annual Hours of Operation = 8,760 hours (3-shift, continuous operation)

Annual electricity costs =
(77.88 kW)x (8,760 hours)x($0.05/kWh) X .65
= $22,172

reading of real power obviating the need to estimate power factor. (In fact, the use of a wattmeter and separate readings of amps and voltage are usually used to determine the actual power factor.)

Direct measurement of motor current is not always practical. "Hot" measurement of a motor current exposes workers to risk and may not be feasible in an industrial environment due to exposure of the power connections to moisture or contaminants.

Use of Pump Curves.

Another method of determining pump power consumption is to record the pressure readings associated with pump operation and to use the pump's performance curve to determine the corresponding brake horsepower. Pump performance curves use total head to indicate pump output; consequently, this method requires pressure instrumentation on the suction and discharge sides of a pump.

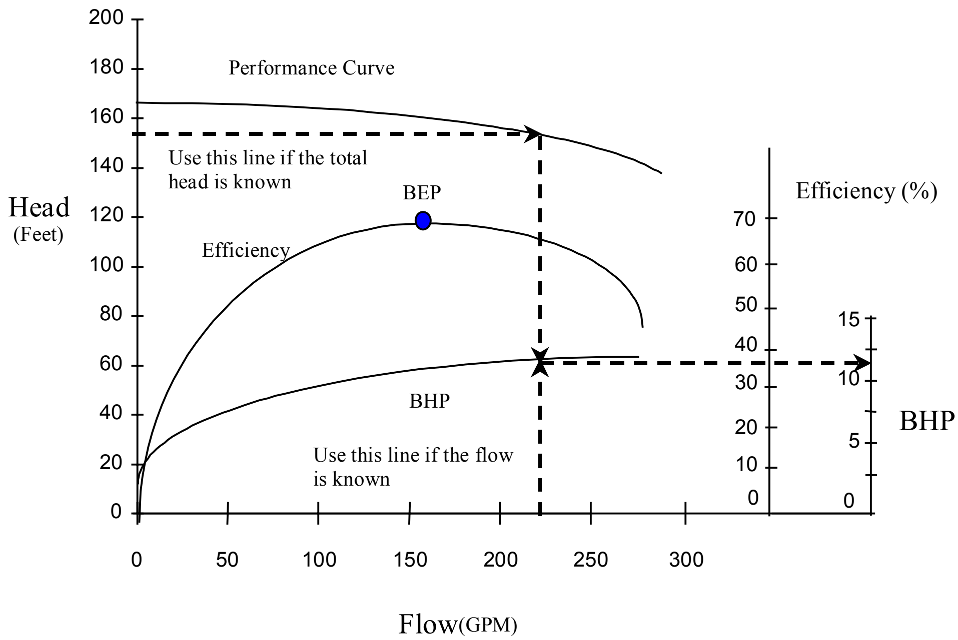


Figure 1 Use of Pump curves to Determine Power Consumption

Once the pressure on the discharge and suction sides of a pump are known, the total head developed by the pump can be calculated. The head developed by the pump corresponds to a horsepower reading as shown in Figure 1. The *Pump Curves* text box then shows how to calculate annual energy costs.

This approach may be limited because in many applications, there is no gauge on the suction side of the pump. Unless a reasonable assumption of suction pressure is available (for example the height of a fluid level in a vented tank that directly feeds into the pump suction), the total head developed by the pump cannot be known.

Pump Curves

Annual Electricity Costs = Pump BHP/Motor Efficiency x (Annual Hours of Operation) x (Electricity Cost in $/kWh) x (Load Factor)

Assumptions:
- Either total pump head or pump flow rate is known
- Motor Efficiency = 95 percent
- Load Factor = 65 percent
- $0.05/kWh unit electricity cost

For example:
- Total head = 155 feet
- Reading from the BHP line, pump BHP = 11 horsepower

Annual electricity costs = (11 bhp)*(0.746 kW/hp)* (1/0.95)*(8760 hrs)*(0.05$/kWh)*(0.65) = $2,459

Another potential limitation is the accuracy of pressure gauges used in many industrial applications. These pressure gauges are often not calibrated on a regular basis and may not be sufficiently accurate. In some cases, these gauges also lack the required precision necessary to accurately determine power consumption. This is particularly true for pumps that have relatively flat performance curves in which a small difference in head makes a big difference in flow and BHP. If the system gauge does not have the necessary precision, then a test gauge should be installed. In many systems, the pipe fittings used for pressure gauges have secondary connection ports to accommodate calibration equipment. These ports are well-suited for using a separate test gauge that is more accurate than the system gauge.

To use the pump curve, the total pressure developed by the pump must be converted to a head value. This conversion requires two key factors: the density of the system fluid and an estimate of the velocity, or dynamic, head. Fluid density can typically be determined by measuring the temperature of the fluid and using an table of properties for that fluid to find the corresponding density.

The velocity head is more difficult to determine since it requires knowing the pump flow rate which, in turn, requires knowing the pump head. However, since velocity head is typically much smaller than the static head, by making a reasonable assumption of the fluid velocity, the velocity head can be approximated. For example, in some cooling systems, to minimize flow noise, a maximum flow velocity is used as a design guideline. Using a common maximum velocity of 10 feet/second which corresponds to a velocity head of only 1.55 feet -- the value of the error associated with this number is probably minor compared to other errors associated with estimated annual energy consumption.

Alternatively, if a pump discharge line already has a flowmeter, then it provides an ideal opportunity to determine the flow rate, which, in turn, can be used to determine the pump's operating point along its performance curve. Also, portable flowmeters that clamp onto the pipe can be used to measure flow rate. In general, portable flowmeters work relatively well on systems that have homogenous fluids and long straight runs of pipe. However, the accuracy of these instruments deteriorates if the fluid contains particulates or vapor or if the flow profile is highly non-uniform.

Energy and Demand Charges --Understanding Your Electricity Bill

The calculations shown previously use electricity rates stated in terms of dollars per kilowatt-hour ($/kWh). However, electric utilities bill industrial customers using more complicated rate structures. These typically include both energy ($/kWh) and demand charges ($/kW), and have different rates depending on the level of consumption and time of year. Demand charges are based on the peak demand for a given month or season and can have significant impacts on electricity costs for some customers. When the economic impacts of efficiency measures are calculated, the marginal cost of the electricity needs to be considered, taking into account energy and demand charges, seasonal rates, and different rates for different levels of consumption.

Maintenance Considerations and Life Cycle Costs

In addition to the cost of energy consumption, maintenance costs can be a significant portion of a pumping system's total operating costs. There are two principal types of maintenance: preventive maintenance and repair. Preventive maintenance (PM) is intended to improve system reliability, reduce the risk of unplanned downtime, and avoid expensive failures. Repair refers to the parts and labor required to troubleshoot and fix equipment that is performing improperly or has broken. In general, preventive maintenance is less costly than repair. A well-designed PM schedule minimizes the need for repairs by detecting and resolving problems before they develop into more serious issues.

In much the same way a preventive maintenance schedule minimizes expensive repairs, a well-designed system can avoid higher-than-necessary operating costs. Using a life cycle cost perspective during initial system design or during the planning of system upgrades and modifications, can provide both lower operating costs and improved system reliability. Components of life cycle cost include initial equipment cost, energy consumption, maintenance, and decommissioning.

A highly efficient pumping system is not merely a system with an energy-efficient motor. Overall system efficiency is the key to maximum cost savings. Often users are only concerned with initial cost, accepting the lowest bid for a component, while ignoring system efficiency. To achieve optimum pumping system economics, users should select equipment based on life cycle economics and operate and maintain the equipment for peak performance.

SECTION 3 WHERE TO FIND HELP

Table of Contents

THE MOTOR CHALLENGE

This section describes the Motor Challenge, a national effort sponsored by the U.S. Department of Energy aimed at improving the performance of electric motor systems.

Overview

The United States Department of Energy.s (DOE) Motor Challenge program is a part of the DOE Office of Industrial Technologies (OIT). Other programs of interest within this office include the Steam Challenge, Compressed Air Challenge, and the Industries of the Future research program. Further information on these programs is available through the Motor Challenge Clearinghouse at (800) 862-2086, or via the Internet at www.oit.doe.gov.

Motor Challenge is an industry/government partnership with a goal of 9 billion kilowatt-hours per year of industrial electricity savings by the year 2010. If all financial viable motor-systems related projects were implemented by industry, the energy savings would total 75 to 122 billion kWh/year, including manufacturing and non-manufacturing (mining, agriculture, oil and gas extraction). This amount of energy savings:

- will increase US industry.s overall motor system energy efficiency by 12 percent;
- will reduce carbon emissions by 20 million metric ton carbon (MMTC) equivalent per year, which is equivalent to removing approximately four million cars from the road.

The Motor Challenge program distributes information, tools, case studies and best practices for energy-efficient electric motor system technology and applications. This information is available through the Motor Challenge Information Clearinghouse, which provides reliable, up-to-date information about the practicality and profitability of electric motor system strategies and decisions. Resources available from the Clearinghouse include sourcebooks, fact sheets, best practice case study examples (known as Showcase Demonstration summaries), and information about educational and training opportunities. The Clearinghouse can be reached by phone at (800) 862-2086, or via the Internet at http://www.motor.doe.gov.

The Motor Challenge Program also offers decision support tools such as the MotorMaster+ software. This package supports motor and motor systems improvement planning through the identification of the most efficient motor for a given repair or motor purchase decision, and ASDMaster, which aids in the selection of adjustable speed drives (see the *Resources and Tools* section for further information on these software packages.)

Additionally, the Motor Challenge Program sponsors Showcase Demonstration projects. Summaries of these projects are available through the Clearinghouse. Motor Challenge *Showcase Demonstration* case studies provide examples of how companies have undertaken improvements in their electric motor systems and have benefited from verified energy savings and related improvements in waste reduction and productivity.

Motor Challenge uses *Industry Partnerships* to seek to change the structure of the motor system market by working collaboratively with suppliers, manufacturers, expert advisors, and users of motor-driven equipment such as fans, pumps, and air compressors. The purpose of these collaborations is to develop and identify delivery mechanisms for new educational products, materials, workshops, software tools, and services that focus on expanding the Motor Challenge portfolio beyond energy-efficient motors and drives. Industry Partnerships seek to build and strengthen networks of relationships among original equipment manufacturer trade associations, industrial end-users, and energy providers to create new types of information, tools, and technical materials. Motor Challenge.s involvement with the Hydraulic Institute, the Compressed Air and Gas Institute (CAGI) and others are examples of this effort.

The Systems Approach

The Motor Challenge Program encourages use of the "Systems Approach" in motor system design and analysis. The systems approach seeks to increase the efficiency of electric motor systems by shifting the focus from individual components and functions to total system performance (see Figure 1). When applying the systems approach, process system design and manufacturing best practices seek to optimize performance in the entire process system, and then on selecting components and control strategies which best match the new, reduced process load. The steps involved in accomplishing a system optimization would involve: characterizing the process load requirements; minimizing distribution losses; matching the driven equipment to load requirements; controlling the process load in the most optimal manner considering all cycles of the process load; and properly matching the motor and drive to each other as well as the load.

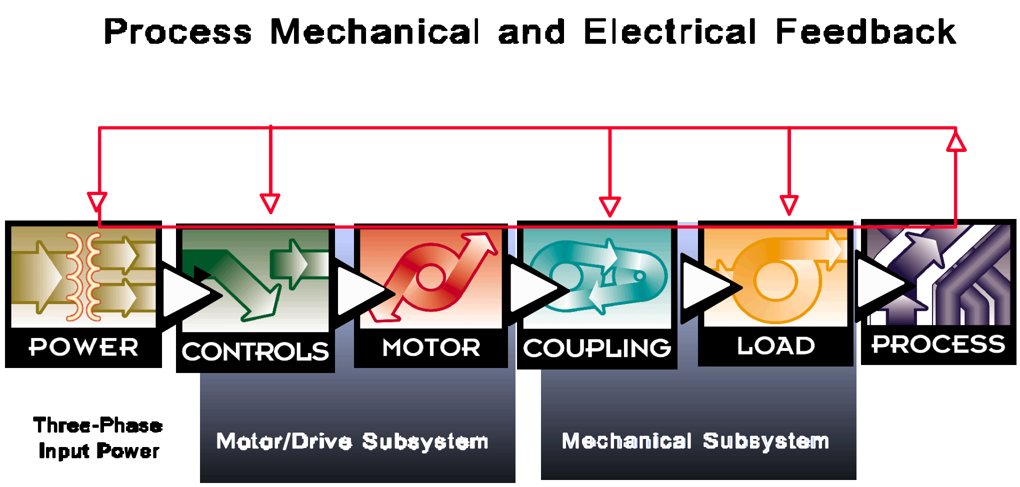


Figure 1 Motor System Design

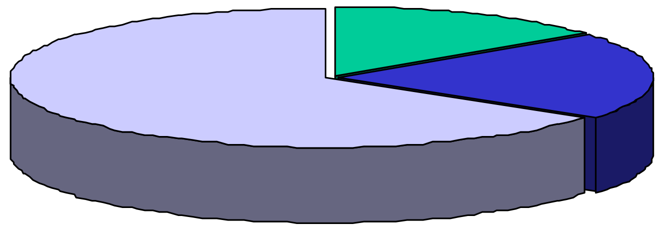


Figure 2 Breakout of Manufacturing Motor System Savings

Figure 2 shows that two-thirds of the potential manufacturing motor system savings are .system. related, demonstrating that management decisions and technical actions that support a systems approach at the corporate and plant level will be the key to achieving large scale energy efficiency improvement in manufacturing motor systems.

Motor Systems Market Study

A recent study commissioned by the United States Department of Energy has estimated that optimizing industrial motor systems through the implementation of mature, proven, cost-effective energy-savings techniques can reduce industrial energy consumption by 75 to 122 billion kWh per year, or up to $5.8 billion per year. These estimates include only the energy savings, and do not factor in other benefits likely to result from optimization, such as improved control over production processes, reduced maintenance, and improved environmental compliance. This study is based upon on-site surveys of 265 industrial facilities in the US, in a probability-based sampling of the US manufacturing sector. The study, titled "United States Industrial Motor Systems Market Opportunities Assessment", can be downloaded from the Motor Challenge web site (http://www.motor.doe.gov), or obtained through the Motor Challenge Clearinghouse.

The other key findings from this study are as follows:

- Industrial motor systems represent the largest single electrical end use in the American economy. In 1994, industrial electric motor systems used in production consumed over 679 billion kWh, or roughly 23 percent of all electricity sold in the United States.
- Improvements to the major fluid systems . pumps, fans, and air compressors . represent up to 62 percent of potential savings. This estimate does not include savings associated with improving the efficiency of the motors driving these systems. The technical aspects of optimizing pump, fan, and air compressor systems are well understood, but not widely implemented.

- Motor systems energy use and energy savings are highly concentrated by industry and size of plant. Roughly 3,500 manufacturing facilities (1.5 percent of the total number of plants) account for nearly half of all motor system energy use and potential savings in the manufacturing sector
- Overcoming the barriers to adoption of efficient motor systems purchase and management practices is difficult. These barriers include: conflicting priorities for capital investment, long capital replacement cycles, under-staffing and under-training of plant maintenance and management functions, and conflicting motivations among equipment suppliers.

Potential motor system energy savings carry significant impacts for the national economy and environment:

- Potential savings would reduce greenhouse gas emissions by 15.3 to 26.0 million metric tons of carbon per year.
- These savings are equivalent to removing 3.2 to 5.4 million cars from the road.
- The monetary value of these savings (after accounting for the price effects of self-generation) is $3.0 to $5.0 billion per year.
- In addition to energy savings, these improvements will yield a number of other economic benefits, including increased control over manufacturing processes, reduced maintenance, and higher levels of quality control.

Table 1 below (originally presented in the US DOE study) displays motor systems energy use and potential savings per establishment in the ten four-digit SIC groups with the highest annual motor energy consumption. In all these industries, the annual cost of motor system energy in a typical plant exceeds $1 million; in steel mills the energy cost is $6 million. Potential savings at the typical plant are also very large, ranging from $90,000 per year in the Industrial Organic Chemicals sector to nearly $1 million per year in petroleum refineries.

The right-hand column of Table 1 shows potential energy savings as a percentage of operating margin. These figures suggest the potential impact of motor energy savings on the bottom line. The process industries listed in Table 1 operate on very thin margins, that is: the difference between revenues from sales and variable costs, including labor, materials, and selling costs. In 1996, operating margins for the ten groups listed below ranged from ten to 24 percent, and clustered around 16 percent. Thus, even relatively small increases in operating margin can have a significant impact on profitability.

DOE Activities Related To Industrial Pumping Systems

The US Department of Energy is involved in several activities through the Motor Challenge program that are specifically related to industrial pumping systems, including the development and publishing of this sourcebook. Motor Challenge has sponsored numerous workshops on pump systems optimization for the water/wastewater industry. A software tool designed to help pump users quickly determine whether a pumping system is operating effectively will soon be available through Motor Challenge. (See the Pumping System Assessment Tool summary in the *Resources and Tools* section for more information.) Also, Motor Challenge has representatives active in the Hydraulic Institute.s Life Cycle Cost Committee, which is preparing materials to aid pump users seeking to reduce energy and total system costs. More information on this committee's work is contained in the Hydraulic Institute summary in the *Directory of Contacts* section.

Further information on all aspects of the Motor Challenge Program is available by calling the Motor Challenge Clearinghouse at:

1 (800) 862-2086

Information is also available at the Motor Challenge web site:

http://www.motor.doe.gov

This site contains current information on planned workshops and training opportunities in areas such as pumping systems optimization.

Table 1
Financial Impact of Motor Consumption and Savings: Selected Industries

Industry Groups	Motor Sys. Costs/Estab.	Motor Energy Costs / Total Operating Costs	Savings per Estab. Per Year	Savings as % of Operating Margin
Paper Mills	4.6 million	6.5 %	$659,000	5 %
Petroleum Refining	5.6 million	1.4 %	$946,000	1 %
Industrial Inorganic Chemicals, nec.	1.6 million	10.4 %	$283,000	6 %
Paperboard Mills	3.0 million	6.4 %	$492,000	5 %
Blast Furnaces and Steel Mills	6.0 million	2.1 %	$358,000	2 %
Industrial Organic Chemicals, nec.	1.3 million	1.0 %	$91,000	1 %
Industrial Gases	1.1 million	21.7 %	$116,000	13 %
Plastics Materials and Resins	1.5 million	1.5 %	$121,000	1 %
Cement, Hydraulic	2.2 million	9.6 %	$219,000	4 %
Pulp Mills	1.7 million	6.7 %	$483,000	5 %

Sources: MECS 1994, Bureau of Economic Analysis 1997, Census of Manufactures 1993

DIRECTORY OF CONTACTS

The following organizations can provide more information on improving the performance of pumps and pumping systems.

The Motor Challenge

The Motor Challenge Information Clearinghouse
P.O. Box 43171
Olympia, WA 98504-3171
Phone: (800) 862-2086
Fax: (360) 586-8303
http://www.motor.doe.gov

The Clearinghouse is a one-stop-shop for resources and information on improving electric motor systems, including pumping systems.

Hydraulic Institute (HI)

9 Sylvan Way
Parsippany, NJ 07054-3802
Phone: (973) 267-9700
Fax: (973) 267-9055
http://www.pumps.org *(available mid-1999)*

HI is a non-profit industry association for manufacturers of pumps and pump systems, promoting the effective, efficient, and economic use of pump products worldwide. By developing standards that define and control the performance, testing, life, and quality of pumps and pump products, HI helps eliminate misunderstandings between manufacturers, purchasers, and pump users. These voluntary standards help the purchaser to select and obtain the pump best suited to a particular need. All HI standards are developed in accordance with ANSI guidelines. HI is also a source for other pump-related publications and educational products.

HI has recently established a Life Cycle Cost Committee to focus industry attention on opportunities for pumping system improvements that will lead to reduced total cost of ownership for pumping systems. This committee plans to prepare materials that will present the life cycle cost concept to specifiers, manufacturers, distributors, owners, and users of pump systems. The committee is developing a method of calculating life cycle cost that will include design, procurement, installation, operation, maintenance, repair, decommissioning and disposal of pump systems. The committee also plans to adopt or develop tools that will allow the life cycle cost of alternative pump systems to be compared on a consistent basis. This committee is cooperating with EUROPUMP, a European pump manufacturers trade association, in a similar effort, the “Enersave” program, for the European community.

American National Standards Institute (ANSI)

11 West 42nd Street
New York, New York 10036
Phone: (212) 642-4900

Fax: (212) 398-0023

ANSI is a private, non-profit membership organization whose goal is the administration and coordination of standards for a broad range of goods and services for the United States. ANSI maintains a number of codes for centrifugal pumps, positive displacement pumps, and fire-protection pumps, developed by the Hydraulic Institute and other organizations.

American Petroleum Institute (API)

1220 L Street, NW
Washington, DC 20005
Phone: (202) 682-8000

API is a trade association consisting of exploration and production, transportation, refining, and marketing organizations from the petroleum industry. API has developed standards for machinery in petroleum applications.

Society of Tribologists and Lubrication Engineers (STLE)

840 Busse Highway
Park Ridge, IL 60068-2376
Phone: (847) 825-5536
Fax: (847) 825-1456

The STLE is a professional society that focuses on issues of wear and machine reliability which translates to an interest in predicting and avoiding failures in bearings and mechanical seals.

American Society of Mechanical Engineers (ASME)

345 E. 47th St.
New York, NY
10017-2392
Phone: (800) 843-2473
Fax: (202) 429-9417

ASME is a professional society with interests in the design and operation of machines and components. ASME reports on technology developments that can impact material selection and pump design.

RESOURCES AND TOOLS

A wide range of information is available on the application and use of pumps. This section of the *Sourcebook* will focus on resources and tools in the following formats:

- Books and Reports,
- Other Publications,
- Government and Commercial Statistics and Market Forecasts,
- Software,
- Training Courses, and
- Other Sources of Information

Note: the description accompanying the following sources have generally been taken directly from the publisher/author/developer. Inclusion of these sources does not imply endorsement by the US Department of Energy.

Books and Reports

Cameron Hydraulic Data, 18th Edition

Author: Ingersoll Dresser
Description: This comprehensive text includes hydraulic principles and the properties of liquids, selected formulas and equivalents, friction data, steam and electrical data tables, and a full-color selection guide of Ingersoll-Dresser products. This edition also provides detailed information on reciprocating pumps, pulsation analysis, and system piping.
Available from: Compressed Air Magazine
253 E. Washington Avenue
Washington, NJ 07882
Phone: (908) 647-6800
Fax: (908) 604-8195
Website: http://ingersoll-rand.com:80/compair/june97/data_ad3.htm

Care and Use of Subsurface Pumps, 3rd Edition

Author: American Petroleum Institute (API)
Description: This book provides recommendations for handling and using subsurface pumps. Included are general characteristics of the pump types standardized in Spec 11AX, inspection of pumps for compliance with API standards, precautions in transporting and handling, operation, and proper assemble/disassembly of pumps.
Available from: American Petroleum Institute
P.O. Box 1327
Merrifield, VA 22116
Phone: (202) 682-8159
Fax: (202) 962-4776
Website: http://www.api.org

Centrifugal and Axial Flow Pumps: Theory, Design, and Application

Author: Alexey J. Stepanoff
ISBN: 0894647237
Description: This pump industry standard includes sections on ranges of head per stage, total pressure, temperature, speed, and size. Theoretical aspects and design procedures are also covered.
Available from: Krieger Publishing
P.O. Box 9542
Melbourne, FL 32902
Phone: (407) 724-9542
Fax: (407) 951-3671
Website: http://web4u.com/krieger-publishing/

Centrifugal Pump Clinic, 2nd Edition

Author: Igor Karassik
Description: This volume (#68) of the .Mechanical Engineering Series. serves as an up-to-date working guide for plant and design engineers involved with centrifugal pumps. Sections include: application, pump construction, installation, operation, maintenance, and field troubles.
Available from: Marcel Dekker
270 Madison Avenue
New York, NY 10016
Phone: (212) 696-9000
Phone: (800) 228-1160
Website: http://www.dekker.com

Centrifugal Pump Sourcebook

Author: John W. Dufour and William E. Nelson
ISBN: 0070180334
Description: A guide to centrifugal pump operation and maintenance, this book also offers advice on installation and troubleshooting. It features guidance on pump technology, curves, hydraulic loads and bearings, mechanical seals, vertical pumps, alignment techniques, and suction performance.
Available from: McGraw-Hill
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P.O. Box 545
Blacklick, OH 43004-0545
Phone: (800) 722-4726
Fax: (614) 755-5645
Website: http://www.mcgraw-hill.com/

Centrifugal Pump User. s Guidebook: Problems and Solutions

Author: Shmariahu Yeddiah
ISBN: 041299111X
Description: This reference text provides complete and up-to-date information on how to attain and maintain optimum performance from centrifugal pumps. It offers a hands-on approach

to diagnosing and solving problems that will help all pump users, from novice to experienced. It includes the cause and effect of recirculation as well as its function, specific aspects of cavitation, problems encountered during tests, and much more. The text was specifically written for designers, manufacturers, and researchers.

Available from: Chapman & Hall
2 Boundary Row
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SE1 8HN
England
Phone: 0171-865-0066
Fax: 0171-522-9623

Centrifugal Pumps, Second Edition

Author: Igor J. Karassik and J. Terry McGuire
ISBN: 0412063913
Description: This up-to-date reference book includes practical information on all aspects of centrifugal pumps. With classifications of various forms of centrifugal pumps and the essential features of pump construction, application, installation, operation, and maintenance, this second edition provides owners, designers, operators, and maintenance personnel the basic information on how to: determine pump ratings that best meet application requirements; operate pumps in the most efficient and reliable manner; maintain pumps to reduce the number of needed overhauls; and ensure pumps remain in peak condition.
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Centrifugal Pumps and Allied Machinery

Author: Harold Anderson
ISBN: 1856172317
Description: This book is designed for engineers and designers concerned with centrifugal pumps and turbines and includes statistical information derived from 20,000 pumps and 700 turbines with capacities ranging from 5 gpm to 5,000,000 gpm. The statistical analyses suggest practical methods of increasing pump performance and provide valuable data for new design aspects.
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Website: http://www.elsevier.nl/inca/homepage/about/custserv/

Centrifugal Pumps: Design and Application

Author: Val S. Lobanoff and Robert R. Ross
ISBN: 087201200X
Description: This book includes the following chapters: Specific Speed & Modeling Laws; Impeller Design; General Pump Design; Volute Design; Design of Multi-Stage Casing; Double-Suction Pumps & Side-Suction Design; NPSH; Vertical Pumps; Pipeline, Waterflood & CO_2 Pumps; High Speed Pumps; Double-Case Pumps; Slurry Pumps; Hydraulic Power Recovery Turbines; Chemical-Pumps Metallic & Nonmetallic; Shaft Design & Axial Thrust; Mechanical Seals; Vibration & Noise in Pumps; Alignment; Rolling Element Bearings & Lubrication; and Mechanical Seal Reliability.
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Website: http://www.gulfpub.com/scitech.html

Encyclopedia of Chemical Processing and Design

Author: John J. McKetta
ISBN: 24968
Description: This text provides engineers with up-to-date information on chemical processes, methods, practices, products, and standards in the chemical and related industries.
Sections include: Pumps, Bypass; Pumps and Compressors, Efficiency Monitoring; Pumps, Conversion Monograph; Pumps, Efficiency; Pumps, Flow Estimates; Pumps and Motors Cost; Pumps, Performance from Motor Data; Pumps, Plastic, Selection of; Pumps, Testing Pitfalls; and Pumps, Unusual Problems.
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Phone: (800) 228-1160
E-Mail: marketing@dekker.com
Website: http://www.dekker.com

Handbook of Fluid Dynamics and Fluid Machinery, Volume 3 (Application of Fluid Dynamics)

Author: Joseph A. Schetz and Allen E. Fuhs
Description: This volume provides information on static components of fluid machinery, positive displacement compressors, pumps and motors, turbo machinery, and hydraulic and pneumatic systems.
Available from: John Wiley & Sons

605 3rd Avenue
New York, NY 10158
Phone: (212) 850-6000
Fax: (212) 850-6088
E-Mail: info@qm.jwiley.com
Website: http://www.wiley.com

Hermetic Pumps

Author: Robert Neumaier, Editor
ISBN: 00884158012
Description: This book reviews past achievements and provides the impetus for further development of sealless pumps. Analyses of the present state of technology of hermetic centrifugal pumps and rotary displacement pumps are provided along with detailed descriptions of the design, performance, and application of such machines.
Available from: Gulf Publishing
Book Division
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Houston, TX 77252
Phone: (713) 520-4444
Fax: (703) 520-4438
Website: http://www.gulfpub.com/scitech.html

HVAC Pump Handbook

Author: James B. Rishel
ISBN: 0070530335
Description: Covering one of the most important areas of mechanical engineering, this is a reference of the design, application, installation, and maintenance of all types of HVAC pumps. Filled with case studies and problem solving sections, the book offers concrete methods for achieving efficient pump operation.
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Phone: (800) 722-4726
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Website: http://www.mcgraw-hill.com/

Hydrodynamics of Pumps

Author: Christopher Brennen
ISBN: 019564422
Description: This work covers the theory of pumps and fluid flow. Among the topics are: cavitation damage, parameters and inception; bubble dynamics, damage, and noise; pump vibration; unsteady flow; and radial and rotordynamic forces.
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Oxford OX2 6DP, UK

Leak-Free Pumps and Compressors

Author: G. Vetter
ISBN: 1856172309
Description: This practical reference manual is written for users of leak-free or seal-less pumps or compressors. It is designed to allow the user to understand various design properties of leak-free pumps and select the appropriate pump or compressor to ensure leak-free systems, whatever the application.
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Metering Pump Handbook

Author: Robert E. McCabe, Philip G. Lanckton, and William V. Dwyer, all with Pulafeed Division/CLEVEPAK Corporation
ISBN: 0831111577
Description: The handbook is designed for metering pump designers and engineers working in all industries. It presents the basic principles of the positive displacement pump; develops in-depth analysis of the design of reciprocating metering pumps and their piping systems; and demonstrates the practical implementation of these concepts through examples of actual pump applications. Easily accessible information includes: fundamentals of metering pump operation, principles of pump and piping system design, guidelines for selection of pump construction materials, procedures for installation, operation, and maintenance of metering pumps, and general formulas, tables, charts, and pumping system layouts.
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Optimization of Unit Operations: Boilers, Chemical Reactors, Chillers, Clean Rooms, Compressors, Condensers, Heat Exchangers, HVAC Systems, Pumping Stations, Reboilers, Vaporizers

Author: Bela G. Liptak
Description: This text examines the technical and practical applications of plant multivariable development control.
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Fax: (715) 445-4087

Performance Optimization Training Manual

Description: This 300 page comprehensive manual offered by the Energy Center of Wisconsin covers optimization techniques that are applicable to fan, pump and blower systems. The book reviews turbomachine fundamentals; system fundamentals; performance optimization opportunities; feasibility study methodology, electrical metering, field performance testing, adjustable speed drives in performance optimization, and more.

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Madison Wisconsin, 53705
Phone: (608) 238-4601
Fax: (608) 238-8733
E-mail: industrial@ecw.org
Website: http://www.ecw.org

Progress In Pumps

Author: Jay Matley, Chemical Engineering Magazine
ISBN: 0070409331
Description: A compilation of 26 articles from .Chemical Engineering Magazine.. Among the subjects covered are advances in pump technology, positive-displacement pumps, centrifugal pumps, mechanical seals, and pump drives.

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Pump Application Desk Book, 3rd Edition

Author: Paul N. Garay, P.E.
Description: Newly revised, this is a complete guide to help end users solve problems associated with all types of pump applications. Examined in detail are pumping of viscous fluids, specifying variable speed pumping controls, use of pump curves, slurries and their associated problems, pump seals, and pump categories and uses. The text is illustrated with numerous nomograms, tables, and figures to guide the user in making the optimum selection of pumps and avoiding common operating problems

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Phone: (800) 922-0579
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Pump Characteristics and Applications

Author: Michael W. Volk
ISBN: 0-8247-95806-6
Description: This reference text provides a practical introduction to pumps and the tools necessary to select, size, operate, and maintain pumps properly. Written in a hands-on style, the book highlights the interrelatedness of pump engineering from system and piping design to installation and start-up. Included is an IBM-compatible disk that illustrates how software can facilitate the sizing and analysis of piping systems.
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Pump Handbook - Second Edition

Author: Igor J. Karassik, Worthington Corp.; William C. Krutzsch, Worthington Corp.; Joseph P. Messina, Public Service Electric and Gas Company; and Warren H. Fraser, Worthington Corp.
ISBN: 0071005277
Description: This fully revised, expanded edition provides fast, accurate answers to all kinds of pump-related questions. It includes information on current data on pump design procedures, selection and purchase of pumps, applications, pump drivers, testing procedures, troubleshooting and maintenance, and numerous topics not treated in any other work on pumps. Each section is written by an expert in the field.
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The Pump Handbook Series: 1997 Edition

Author: Pumps and Systems Magazine
Description: Practical how-to articles authored by pump experts and experienced users, compete with photos, charts, and figures. This series of five volumes (Centrifugal Pumps, Positive Displacement Pumps, Mechanical Seals & Sealing Systems, Pump Maintenance & Reliability, and Pump & System Troubleshooting) describes proven ways to increase a pumps. operating performance and reliability. It supplies machinery engineers, maintenance personnel, and managers with an overview of pump reliability improvements and techniques for maintenance and troubleshooting. Also available on CD-ROM.
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Fax: (970) 221-2019
E-Mail: davehill@csn.net
Website: http://www.pump-zone.com/handbook.htm

Pump Operation & Maintenance

Author: Tyler G. Hicks
ISBN: 0070993491
Description: This practical guide is designed for plant operating and management personnel. It demonstrates how to operate and maintain pumps used in industrial, municipal, central station, marine, and institutional settings. Specific step-by-step instructions for installing, starting up, operating, maintaining, and overhauling are provided for every major class and type of pump.
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Website: http://web4u.com/krieger-publishing/

Pump Standards

Author: Hydraulic Institute
Description: This set of standards is designed to facilitate communication and understanding between manufacturers, purchasers, and users. These standards are also intended to assist the purchaser in selecting the proper product for a particular application.
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Fax: (201) 267-9055

Pump Users Handbook, 3rd Edition

Author: F. Pollak
ISBN: 0854611223
Description: This handbook discusses changes in pump technology, standards, materials, installation, operation, and maintenance that have taken place in the past decade. Subjects include principles of pumping; main classifications of pumps and their characteristics; significance of physical properties of liquids; liquid flow into the pump (suction performance); defining the total pump head or pressure; stuffing-box and mechanical seal; choice of pump materials; how to inquire for, select, and order pumps; electric pumps and drives; pipeline systems and valves; pressure surges and control in pipelines; how to test pumps; hints for users; and health and safety.
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Pump Users Handbook, 4th Edition

ISBN: 1856172163
Description: This book assists in ordering pump equipment and recognizing fundamental operating problems. The principles of pumping, hydraulics, and fluids are discussed, as are the various criteria necessary for pump and ancillary equipment selection.
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Pumping Manual, 9th Edition

Author: Christopher Dickenson
ISBN: 0856172155
Description: Written in an easy-to-follow manner, this volume is full of practical information and data on the selection, installation, operation, and maintenance of industrial pumps for most applications. The contents follow a logical sequence of pump evolution, performance and characteristics, pump types, practice and operation, and much more.
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Pumping Station Design, 2nd Edition

Author: Robert L. Sanks
ISBN: 0750694831
Description: This book covers all phases of the design of pumping facilities for water, wastewater, and treatment plant sludges. Topics include hydraulic fundamentals, electricity and theory of pumps, selection of pumps and drivers, system design, piping layout, instrumentation, heating and ventilating, and noise control.
Available from: Butterworth-Heinemann
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Pumps/Compressors/Fans: Pocket Handbook

Author: Nicholas P. Cheremisinoff and Paul N. Cheremisinoff

Description: This handbook provides a concise presentation of the fundamentals -- design, function, and application -- of pumps, compressors, and fans. It is organized for easy reference and illustrated with more than 80 photographs, diagrams, and other schematics. This text is designed to help engineers and other plant operations personnel select and utilize this equipment.

Available from: Technomic Publishing Company, Inc.
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Fax: (717) 295-4538

The Reciprocating Pump: Theory, Design, and Use, 2nd Edition

Author: John E. Miller
ISBN: 0894645994
Description: This book provides detailed information on reciprocating pumps from both designer and user perspectives. Included are details of special pump applications, theory, design, autofrettage of liquid end, polation dampening, and much more.

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Slurry: Transport Using Centrifugal Pumps, 2nd Edition

Author: K.C. Wilson, G.R. Addie, A. Sellgren, and R. Clift
ISBN: 075140408X
Description: This text is a companion to a course offered by the authors at the GIW Hydraulic Laboratory. The first part of the book focuses on the behavior of various sorts of slurry flow, while the latter part concentrates on centrifugal pumps and the interaction between pumps and slurries in pipeline transport systems. This book is designed for engineers and technologists involved in the large scale transportation of slurries.

Available from: Blackie Academic and Professional
A division of Chapman & Hall
2 Boundary Row
London
SE1 8HN
England
Phone: 0171-865-0066
Fax: 0171-522-9623

Submersible Pumps and Their Applications

Author: Harold Anderson
ISBN: 0854610987

Description: In this comprehensive manual, the characteristics and applications of submersible pumps are described in detail. The reader is provided with the necessary information for the selection, operation, and maintenance of all submersible pumps.

Available from: Elsevier Science
Regional Sales Office
Customer Support Department
P.O. Box 945
New York, NY 10159
Phone: (888) 437-4636
Fax: (212) 633-3680
E-Mail: usinfo-f@elsevier.com
Website: http://www.elsevier.nl/inca/homepage/about/custserv/

Sulzer Centrifugal Pump Handbook

Author: Sulzer Brothers Ltd., Sulzer Pump Division
ISBN: 1851664424
Description: This handbook discusses the recent progress made in pump construction looking at experiences gained by CCM-Sulzer and other pump construction industry members. Areas such as cavitation, erosion, selection of materials, rotor vibration behavior, forces acting on pumps, operating performance in various types of circuitry, drives, and acceptance testing are covered in detail. The handbook is directed to planners and operating companies alike.

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Phone: (888) 437-4636
Fax: (212) 633-3680
E-Mail: usinfo-f@elsevier.com
Website: http://www.elsevier.nl/inca/homepage/about/custserv/

Vertical Turbine, Mixed Flow, and Axial Pumps

Author: John Dicmas
ISBN: 0070168377
Description: This book discusses the operating principles and applications of vertical turbine, mixed flow, and axial pumps.

Available from: McGraw-Hill
Customer Service
P.O. Box 545
Blacklick, OH 43004-0545
Phone: (800) 722-4726
Fax: (614) 755-5645
Website: http://www.mcgraw-hill.com/

Wastewater Engineering: Collection and Pumping of Wastewater

Author: Metcalf & Eddy, Inc., George Tchobanoglous, U.C. Davis (ed.)
ISBN: 007041680X
Description: This overview of collection and pumping provides information on applied hydraulics; wastewater flows and measurement; design of sewers; sewer appurtenances; infiltration and inflow; occurrence, effect and control of the biological transformations in sewers; and pumping stations.
Available from: McGraw-Hill
Customer Service
P.O. Box 545
Blacklick, OH 43004-0545
Phone: (800) 722-4726
Fax: (614) 755-5645
Website: http://www.mcgraw-hill.com/

Water Wells and Pump Engineering

Author: A.M. Michael and S.D. Khepar
ISBN: 0074517856
Description: This comprehensive book covers, in detail, both wells and pump engineering. The book is authored by a world renowned authority on wells and irrigation -- Dr. Michael, who has also published a bestseller on irrigation theory and practice.
Available from: McGraw-Hill
Customer Service
P.O. Box 545
Blacklick, OH 43004-0545
Phone: (800) 722-4726
Fax: (614) 755-5645
Website: http://www.mcgraw-hill.com/

Other Publications

Flow Control

Publisher: Witter Publishing Corporation
Description: This monthly magazine addresses fluid handling and control issues. New products, design issues, and technology developments are discussed.
Available from: WPC
84 Park Avenue
Flemington, NJ 08822
Phone: (908) 788-0343
Fax: (908) 788-3782

Pumps and Systems

Publisher: AES Marketing
Description: This monthly magazine discusses issues for the industrial pump user. New products and technologies, problem-solving methods, and design practices are described within

the context of industrial pump applications. This magazine also compiles an annual Users Guide which lists pump manufacturers by pump type.

Available from: Pumps and Systems
123 N. College Ave, Suite 260
Fort Collins, CO 80524
Phone: (970) 221-2006
Fax: (970) 221-2019

Pump Industry Analyst

ISSN: 1359-6128

Description: This monthly newsletter is written for suppliers of pumps and associated equipment, distributors, ancillary equipment manufacturers, trade associations, government bodies, financial institutions, consultants, independent market researchers, and major end users of plant equipment. It is designed to help the reader plan sound business strategies for the future based on accurate and impartial data. The newsletter provides summaries of market and industry statistics, analyses of market information on pump end user industries, and points out key indicators of emerging trends and their impacts on the marketplace.

Available from: Elsevier Science
Regional Sales Office
P.O. Box 945
New York, NY 10159
Phone: (888) 437-4636
Fax: (212) 633-3680
Website: http://www.elsevier.nl/inca/homepage/about/custserv/

World Pumps

ISSN: 0262-1762

Description: This international technical magazine is devoted to the selection, installation, and maintenance of pumps and pumping machinery, components, and ancillary equipment. Purchasers and users of pumps, seals, valves, and motors are provided with an authoritative source of practical and technical information. Included are feature articles from pump users and manufacturers, news of product developments and applications, case studies, business news, financial reports, exhibition coverage, annual directories, and a monthly product finder service.

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Customer Support Department
P.O. Box 945
New York, NY 10159
Phone: (888) 437-4636
Fax: (212) 633-3680
Website: http://www.elsevier.nl/inca/homepage/about/custserv/

Government And Commercial Statistics And Market Forecasts

Morton Research Company˛ s Business Information Reports

Author: Morton Research Company

Description: Morton Research Business Information Reports provide market research, industry norms, economic forecasts, and competitor intelligence. Pump-related reports include: "The U.S. Pumps and Pumping Equipment Industry," "Acquisitions in the U.S. Pump Industry," "The U.S. Market for Centrifugal Pumps," "Distributors of Centrifugal Pumps," "End-Use Markets for Hydraulic Fluid Power Pumps," "U.S. Distributors of Pumps - Listed by State and Brands Carried," "The Financial Condition of the U.S. Pump Industry," "The U.S. Market for Fluid Power Pumps," and "The Export Market for U.S. Pumps."

Available from:
Morton Research Company
7100 W. Camino Real
Boca Raton, FL 33433
Phone: (800) 378-1066
Website: http://mortonresearch.com/

National Market Transformation Strategies for Industrial Electric Motor Systems - Volume I: Main Report

Author: U.S. Department of Energy, Office of Energy Efficiency and Alternative Fuels Policy and Office of Industrial Technologies

Description: This report develops strategic actions for a coordinated and national effort to (1) increase the market penetration of energy-efficient motors and motor-driven systems and (2) encourage movement from a .component-focused. to a .systems-oriented. market. Sections of the report include the following discussions of Process Pump Systems: .Introduction and Summary,. .Equipment and Market Overview,. .Energy Savings Potential - Equipment,. .Efficiency Data, Standards, and Potential Leverage Points,. .Specifying Practices and Behavior,. .System-Level Energy Savings Potential,. and .Strategy Options..

Available from:
Motor Challenge Information Clearinghouse
Office of Industrial Technologies
P. O. Box 43171
Olympia, WA,
800 862 2086
360 586 8303
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585
Phone: (202) 586-7234
Fax: (202) 586-7114

Profile of the International Pump Industry: Market Prospects to 1998

Author: Roisin Reidy

ISBN: 1856172252

Description: This up-to-date assessment offers market potential, key players, market figures, forecasts, analysis, and applications in the international pump industry. Also included is a Directory of Pump Companies with approximately 700 companies, product/application listings, and an index.

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Regional Sales Office
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P.O. Box 945
New York, NY 10159
Phone: (888) 437-4636
Fax: (212) 633-3680
Website: http://www.elsevier.nl/inca/homepage/about/custserv/

Pumps and Compressors (Current Industrial Reports)

Description: This annual report provides data on the quantity and value of manufacturers. shipments, number of producers by product type, exports, and imports. These statistics reflect market trends in the pump and compressor industry.

Available from: U.S. Bureau of the Census
Washington, DC 20233
Phone: (202) 512-1800
Website: http://www.census.gov/econ/www/ip2700.html

U.S. Compressor and Vacuum Pump Markets

Author: Frost & Sullivan

Description: This market research report is divided into sections on positive displacement compressors, dynamic-type compressors, rotary vacuum pumps, liquid ring vacuum pumps, diaphragm vacuum pumps, and diffusion vacuum pumps. In addition to providing forecast information for the total market and all of its segments, the 351-page report also analyzes advancements in technology, materials, and manufacturing processes.

Available from: Frost & Sullivan
90 West Street, Suite 1301
New York, NY 10006
Phone: (212) 964-7000
Fax: (212) 619-0831

United States Industrial Motor Systems Market Opportunities Assessment

Author: US Department of Energy.s Motor Challenge Program

Description: This study, published in December 1998, is based on surveys of motor systems in a probability-based sampling of 265 industrial facilities in the US. This market assessment gives a profile of the stock of motor-driven equipment in U.S. industrial facilities and characterizes the opportunities to improve the energy efficiency of industrial motor systems. It also provides a profile of current motor system purchase and maintenance practices, and is designed to be of value to manufacturers, distributors, engineers, and others in the supply channels for motor systems. It provides a detailed and highly differentiated portrait of their end-use markets. For factory managers, this study presents information they can use to identify motor system energy savings opportunities in their own facilities, and to benchmark their current motor system purchase and management procedures against concepts of best practice.

Available from: Motor Challenge Information Clearinghouse
Office of Industrial Technologies
P.O. Box 43171
Olympia, WA 98504-3171
Phone: (800) 862-2086
Fax: (360) 586-6854
Website: http://www.motor.doe.gov

The U.S. Pump and Compressor Industry

Author: Business Trend Analysts, Inc.

Description: This market research report assesses the market for pumps and compressors by gathering data and conducting analysis. The report presents data of U.S. manufacturers. sales and analysis of end-use demand by industry for pumps and compressors. This report also includes pump and compressor industry statistics, U.S. foreign trade figures, corporate profiles, and a directory of pump and compressor manufacturers.

Available from: Business Trend Analysts, Inc.
2171 Jericho Turnpike
Commack, NY 11725-2900
Phone: (516) 462-5454
Fax: (516) 462-1842

World Pumps #852, Industrial Components and Equipment

Author: The Freedonia Group

Description: World demand for fluid handling pumps is projected to grow more than 7% per year. Fueling gains will be a cyclical upturn in fixed investment in most industrialized countries, and rapid expansion of pump-using industries in developing countries. Data and forecasts are presented by product (e.g., centrifugal pumps, turbine pumps, reciprocating pumps, diaphragm pumps, rotary pumps, oilfield pumps, specialty pumps), by country (e.g., United States, Canada, Mexico, Argentina, Brazil, Colombia, Venezuela, Germany, France, United Kingdom, Italy, Russia, South Africa, Turkey, China, Japan), and by region (North America, South America & Central America, Western Europe, Eastern Europe, Africa/Middle East, and Asia/Oceana). The study also reviews the world pump market environment, evaluates company market shares, and profiles more than 80 selected industry participants.

Available from: Customer Service Department
The Freedonia Group, Inc.
3570 Warrensville Center Road, Suite 201
Cleveland, OH 44122-5226
Phone: (216) 921-6800
Fax: (216) 921-5459
E-Mail: info@freedoniagroup.com
Website: http://www.freedoniagroup.com

Software

All About Pumps

Author: The Animated Software Company

Description: This program includes sections on: .Where Pumps are Used,. .How Pumps Work,. .Types of Pumps,. .Measuring Pump Performance,. .The Right Pump for the Job,. .Historical Background & Some Famous Pumps,. and .The Most Amazing Pump of All.. Also included is a glossary of individual pumps. The program is available on diskette or CD-ROM.

Available from: The Animated Software Company
625 East Bunker Court
Vernon Hills, IL 60061
Phone: (800) 323-4340
Fax: (847) 549-7676
E-Mail: export@coleparmer.com
Website: http://www.animatedsoftware.com

AQUATECH

Author: Technical Application Software (TAS)

Description: AQUATECH is a third-party pump selection software package with the backing of a number of major pump companies in all areas of the pumping industry. It allows the user to simultaneously evaluate pumps for different applications from multiple pump companies. It requires an IBM-compatible PC, DOS Version 3.1 or higher, and 640K RAM.

Available from: Technical Application Software
PO Box 411203
2024
Craighall
JHB
South Africa
Phone: +27 11 325 4813
Fax: +27 11 325 5312
Website: http://www.tassoftware.co.za/

ASDMaster

Author: Electric Power Research Institute and Bonneville Power Administration

Description: This resource is a software package consisting of six modules designed to educate and assist users in the proper application of adjustable speed drives. ASDMaster contains instruction tools that discuss the technology, process effects, and power quality issues associated with ASDs. It also analyzes energy consumption and performance differences between ASDs and constant speed alternatives. Additionally, ASDMaster contains a database module that refers the user to manufacturers of ASDs that can meet the needs of the application.

Available from: Adjustable Speed Drive Demonstration Office
111 Corning Road, Suite 200

Cary, North Carolina 27511
Phone: (800) 982-9294
Fax: (919) 859-5012

AXIAL THRUST & RADIAL THRUST

Author: Pump Technology Services

Description: These two programs calculate axial and radial thrust for a pump. The axial program has many variations to account for different impeller configurations (i.e., with or without vanes). It takes into account S.G., viscosity, wear ring leakage, NPSH, etc. The radial program uses several empirical formulae for different types of volumes, etc. to measure radial thrust for a pump.

Available from:
Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541
E-Mail: pumptech@wantree.com.au

BATCH

Author: Fluid Flow Consultants

Description: BATCH (Batch Analysis Tool for Calculation of Hydraulics) is an IBM-PC program that calculates flowing pressures and temperatures in a pipeline transporting different liquid batches (e.g., diesel, gasoline, LNGs, crude oil, etc.) at the same time. One to fifty batches with different pressure-volume-temperature (PVT) properties may be modeled. Pumps, heaters, and pressure reduction stations may be placed in any configuration. Pump stations may have up to five pump units in series or parallel. A Print-Graph feature allows the graph to be printed on a laser or matrix printer.

Available from:
Fluid Flow Consultants
8004 S. Juniper Avenue
Broken Arrow, OK 74011
Phone: (918) 451-1024
Fax: (918) 451-3365
Website: http://www.galstar.com/~ffc/index.html

BOPUMP

Author: MicroKin Software

Description: This program (Order No. #S058) helps the user save money by choosing the most efficient pump for any liquid network pumping system. BOPUMP calculates discharge head required, regardless of a systems complexity or type of pump used. Calculating discharge head requirements is complex when only one branch is involved, but BOPUMP handles up to 150 branches and will automatically balance all branches with the branch requiring the most head. The program lets the user build a model of the piping systems and takes into account valves, tees, and other nodes.

Available from: Gulf Publishing Company Software

P.O. Box 2608
Houston, TX 77252-2608
Phone: (800) 231-6275
Fax: (713) 520-4433
E-Mail: csv@gulfpub.com

BOS Fluids

Description: BOS Fluids is a steady-state and transient fluid simulator for piping systems and is used by engineers in the plant design industry to analyze situations such as pump startup or shutdown, valve opening or closing, harmonic oscillations of the fluid head or flow rate, time history oscillations of the fluid head or flow rate, column separation, surge vessels, and evaluating Fiberglass Reinforced Piping. The software leads the user through the modeling and analysis process using easy-to-understand terminology. Intelligent meshing technology evaluates the structural model and creates the fluid simulation model automatically for optimal accuracy and efficiency.

Available from: Algor Design World
Publishing Division
150 Beta Drive
Pittsburgh, PA 15238-2932
Phone: (412) 967-2700
Phone: (800) 48-ALGOR
Fax: (412) 967-2781
Website: http://www.algor.com/

CHEMCALC 8, Version 1.4

Author: Gordon S. Buck

Description: This program (Order No. #112) can produce commercially available pump designs to best suit given operating conditions and requirements or revise existing pump curve data for new pumping conditions. It also calculates approximate impeller design and viscosity correction factors based on the Hydraulic Institute charts.

Available from: Gulf Publishing Company Software
P.O. Box 2608
Houston, TX 77252-2608
Phone: (800) 231-6275
Fax: (713) 520-4433
E-Mail: csv@gulfpub.com

C-MAX. /Pump Software

Author: Unicade, Inc.

Description: C-MAX /Pump Software uses a systems analysis approach to calculate break horsepower (bhp), flow rate, and total dynamic head (TDH) of centrifugal pumping system. The pump flow rate or TDH can be calculated from electric motor power consumption data. At part load operation, the changes in pump efficiency, adjustable speed drive (ASD) efficiency and part-load motor efficiency are automatically adjusted and energy use re-computed. Pump characteristic curve, system curve, and efficiency curve are plotted under various operating conditions. Automatic adjustment to the system pressure profile (including control valve) is made when the pump is operated on its base characteristic curve. The off-line modeling and energy conservation studies can be performed for unlimited number of pumps and 'what if" case studies. The software automatically evaluates the interactive impact of changes in process, mechanical, or load variables on energy use. The C-MAX/Pump software includes C-MAX/Pipe module and is integrated with Energy Conservation Measures module, Life Cycle Costing module (includes non-energy benefits calculator), and Performance Charting module.

Available from: UNICADE INC.
13219 NE 20th Street, Suite 211
Bellevue, WA 98005-2020
Phone: (425) 747-0353
Fax: (425) 747-0316
E-mail: unicade@unicade.com
Website: http://www.unicade.com

Engineer. s Aide - Process Engineering Toolbox

Author: Chempute Software

Description: This program combines detailed equipment sizing and pipeline simulations to provide quantitative modelling and sizing capabilities for liquid, gas, two phase, and slurry process systems. The .Pump/Fan/Compressor Sizing. program can help a user determine the fluid transportation requirements of dominant pipeline, non-looped prcess systems. By linking with other programs, an entire system can be sized at once. Equipment Performance data sets are also provided for various manufacturers.

Available from: Job Training Systems, Inc.
P.O. Box 868
Unionville, PA 19375
Phone: (610) 444-0868
Fax: (610) 444-0684
Website: http://www.jobtraining.com

English-Metric Conversion Software Program

Author: Pump-Zone

Description: This program converts flowrates, pressure, power, temperature, viscosity, torque, length, and volume from one system.s units to another. Designed for pump specifiers and users, this software can be used on Windows 3.1 or Windows 95.

Available from: Pump-Zone
123 N. College Avenue, Suite 260
Fort Collins, CO 80524
Phone: (970) 221-2006
Fax: (970) 221-2019
Website: http://www.pump-zone.com/sw-store.htm

Enviro Pro Designer - Design of Waste Treatment Systems

Author: Chempute Software

Description: This program is an environmental process simulator designed to enhance the productivity of engineers and scientists working in the design, development, and assessment of integrated waste recycling, treatment, and disposal processes. Pump operations are one of several operations that can be simulated with this program.

Available from: Job Training Systems, Inc.
P.O. Box 868
Unionville, PA 19375
Phone: (610) 444-0868
Fax: (610) 444-0684
Website: http://www.jobtraining.com

Flexibox Plant Records Program (FLEXILOG)

Author: Flexibox International

Description: This program maintains a database by plant item number on pumps, seals, couplings, and ancillaries. It also records pump, seal, and coupling events and provides pump, seal, and coupling failure analysis.

Available from: Flexibox Inc.
P.O. Box 87010
Houston, TX 77017
Phone: (713) 944-6690
Fax: (713) 946-8252
Website: http://www.flexibox.com/

FLO-SERIES

Author: Engineered Software Inc.

Description: FLO-SERIES software consists of the four programs: (1) PIPE-FLO - piping system design and hydraulic system analysis containing a graphic flow sheet user interface; (2) PUMP-FLO - centrifugal pump selection and evaluation capable of containing over 50 manufacturer.s catalog curves; (3) ORI-FLO - flow meters and orifice sizing; and (4) CON-FLO - control valves. These programs are available individually or as a package. They share and exchange data for complete system analysis, but are not interdependent.

Available from: Engineered Software Inc.
4531 Intelco Loop SE
Lacey, WA 98584-5941
Phone: (360) 412-0702
Fax: (360) 412-0672
E-Mail: sales@eng-software.com
Website: http://www.eng-software.com

GRAFTEC

Author: Technical Application Software

Description: This pump curve plotting software products high quality pump performance curves directly from tested or theoretical data. It enables the user to print pump catalogues in-house at a fraction of the cost of traditional methods.

Available from: Technical Application Software

PO Box 411203
2024 Craighall JHB
South Africa
Phone: +27 11 325 4813
Fax: +27 11 325 5312
Website: www.tassoftware.co.za

GE Energy Savings Analysis

Author: General Electric
Description: This is an interactive energy savings analysis program that uses typical pump and fan characteristic curves for fan and pump applications. It has default data to help users run cases with minimal information from nameplates and the existing system. The program enables users to estimate potential savings from ASDs.
Available from: GE Drive Systems
1501 Roanoke Blvd.
Salem, VA 24153
Phone: (703) 387-7000

HEAD CORRECT and SPEED CORRECT

Author: Pump Technology Services
Description: HEAD CORRECT corrects pump head curves for different diameters using empirical data to calculate effective turndown. SPEED CORRECT corrects pump curves to different speed regime. These are two separate programs.
Available from: Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541
E-Mail: pumptech@wantree.com.au

HYDROFLO II

Author: Engineering Software
Description: This software is a hydraulic system design tool that substantially reduces the time involved in designing systems that convey fluid from point to point. Up to nine parallels (10 pumps) can be modeled. In a matter of minutes an engineer can layout, analyze, and present a number of design alternatives for gravity, pump station, and forced flow systems. Detailed reports of system data are available for output to screen, printer, or file. Graphs of system and pump curves are available on screen and for output to printers. A unique .ANALYZE. option reviews data for critical errors. Requires PC/MS-DOS, 640K RAM and 1 Mb hard disk space.
Available from: Tahoe Design Software
PO Box 8128
Truckee, CA 96162
Website: www.tahoesoft.com

MotorMaster+

Author: Department of Energy Motor Challenge Program

Description: This software package assists users in calculating motor operating costs and tracking the installation and service characteristics for a plant's motor inventory. Additionally, MotorMaster+ contains a database of motors from which the user can select an appropriate model. The software allows consideration of special service requirements such as high starting torque, severe duty, two speed drives, inverter duty, and medium voltage (2300 and 4000 volt) power supplies. MotorMaster+ allows users to track motor loads, maintenance histories, and energy consumption.

Available from: Motor Challenge Information Clearinghouse
P.O. Box 43171
925 Plum St.
Olympia, WA 98504-3171
Phone: (800) 862-2086
Fax: (360) 586-8303
Email: motorline@energy.wsu.edu
Website: http://www.motor.doe.gov/contact.htm

NO-WEAR

Author: Mechanical Solutions, Inc.

Description: This Windows based program predicts wear and erosion for various material selections for the impeller, casing, balancing device, and wear rings and for various pumped liquids. Based on inlet conditions and the manufacturer's NPSHA curve, cavitation damage rate is also predicted. The potential for galling between materials at removable fit and close running clearance locations is also provided.

Available from: Mechanical Solutions, Inc.
1719 Route 10 East, Suite 205
Parsippany, NJ 07054-4507
Phone: (973) 326-9920
Fax: (973) 326-9919
E-Mail: Msi@MechSol.com
Website: http://www.Mechsol.com

NPSHa/System Pipe Loss Software Program

Description: This easy to use, intuitive program determines a user.s existing or proposed pumping system.s NPSH available and system differential pressure or head. This program allows the user to change any of the values and instantly recalculate the parameters they need to know. It works for open or closed systems as well as suction lift applications. The program includes graphical interface that automatically provides schematic drawings of the system based on values entered. For Windows 3.1 or Windows 95.

Available from: Pumps & Systems Software Department
123 N. College Avenue, Suite 260
Fort Collins, CO 80524
Phone: (970) 221-2006
Fax: (970) 221-2019

Website: http://www.pump-zone.com/sw-store.htm

PUMPAL (A&B)

Author: Concepts ETI

Description: These two databases utilize meanline flow models based on extensive past design and test experience. The databases are arranged to allow users to input and catalogue their own previous, on-going, design and test experiences. The interrelated operating modes in both versions of PUMPAL are the design (redesign), analysis, and data reduction. PUMPAL A is an advanced package for highly specialized designers, while PUMPAL B is a basic package of meanline pump analysis software.

Available from:
Concepts ETI, Inc. Headquarters
4 Billings Farm Road
White River Junction, VT 05001
Phone: (802) 296-2321
Fax: (802) 296-2325
Website: http://www.conceptseti.com

PUMPAN

Author: Pump Technology Services

Description: This program offers detailed analysis of a given impeller design. Outputs include calculation of suction and discharge recirculation. NPSH required at total breakdown and 3% head drop. Velocity triangles at entrance and discharge are plotted. Design is optimized for various suggested meridional velocity distributions. This program calculates pump head within 0.5% accuracy at B.E.P. provided it is combined with a correctly designed volute.

Available from:
Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541
E-Mail: pumptech@wantree.com.au

PumpBase

Author: Tahoe Design Software

Description: This program is an advanced pump specification software package for Windows. Fluids handling specialists and hydraulic system designers can specify up to 40 different selection criteria and view graphs of the most efficient pump curves that meet their needs. The software includes a database of thousands of curves from dozens of manufacturers as well as an extensive database of liquid properties. A detailed report is created that can be submitted to pump manufacturers or sales representatives for further application verification and price quotes.

Available from:
Tahoe Design Software
Brian Haulman
PO Box 8128

Truckee, CA 96162
Phone: (916) 582-1525
Fax: (916) 582-8579
E-Mail: tds@ltol.com
Website: http://ns1.ltol.com/~tds/html/pumpbase.html

PUMPCALC - Centrifugal Pump Analysis

Description: Using Affinity Laws, PUMPCALC analyzes the performance of a centrifugal pump at different impeller sizes, speeds, and stages from the pump manufacturer.s data. The speed or diameter required to meet a specific design condition can be calculated. Performance of pumps in series and parallel can be predicted. For high viscosity liquids, the water performance curve is corrected for viscosity using Hydraulics Institute Method. PUMPCALC performs the viscosity correction calculations quickly and accurately using the built-in charts. The resultant performance curves may be plotted on the screen as well as on the connected printer.

Available from: Pam Menon, Marketing Director
Phone: (805) 588-1417
E-Mail: systek@ix.netcom.com
Website: http://www.systek-usa.com

Pumping System Assessment Tool (available soon)

Author: US Department of Energy.s Motor Challenge Program

Description: The Pumping System Assessment Tool (PSAT), developed by the Department of Energy.s Motor Challenge Program, is designed to help pump users quickly distinguish systems that are operating effectively from those where opportunities for improvement exist. The software is based on motor performance characteristics, principally obtained from the Motor Challenge's MotorMaster database and on achievable pump efficiencies from the Hydraulic Institute standard ANSI/HI 1.3, Centrifugal Pump Design and Application._ Users are required to provide information such as nameplate data (e.g., motor size and rated speed), motor current or power, and measured/required flow rate and head._ The software reports potential energy and cost savings that could be achieved if an optimized pump and motor combination was applied. *Note: This software will be available soon. Check with the Information Clearinghouse or Motor Challenge web site for announcements of the software release and associated training sessions.*

Available from: Motor Challenge Information Clearinghouse
Office of Industrial Technologies
P.O. Box 43171
Olympia, WA 98504-3171
Phone: (800) 862-2086
Fax: (360) 586-6854
Website: http://www.motor.doe.gov

PUMPSTUF

Author: Mechanical Solutions, Inc.

Description: This Windows based program includes estimates for the first critical speed of the pump rotor, steady and unsteady axial and radial thrust loads, and levels of allowable imbalance and vibration.

Available from: Mechanical Solutions, Inc.
1719 Route 10 East, Suite 205
Parsippany, NJ 07054-4507
Phone: (973) 326-9920
Fax: (973) 326-9919
E-Mail: Msi@MechSol.com
Website: http://www.Mechsol.com

PUMP TEST

Author: Pump Technology Services

Description: This is a test bed program for evaluation of results. The software is currently being updated to include curve fit and plotting routines.

Available from: Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541
E-Mail: pumptech@wantree.com.au

RAPPID-PATM: Performance Analysis Software

Author: Rotordynamics-Seal Research

Description: This software is used to analyze centrifugal pump performance and impeller geometry generator. Features include the "pump analysis mode" which determines head and efficiency based on user specified impeller geometry.

Available from: Rotodynamics-Seal Reserach
Website: http://www.rsr.com

RING SEAL, BEARING LIFE, STRESS, and WEIGHTS

Author: Pump Technology Services

Description: RING SEAL calculates fluid loss through an impeller neck ring and examines slurry type sealing arrangements for hydrodynamic effects in seal. BEARING LIFE calculates expected bearing life and is used with AXIAL THRUST and RADIAL THRUST programs. STRESS calculates stress put on pump parts and includes calculation of moments defection for various temperatures and pressures. WEIGHTS calculates impeller weights for casting purposes. These are four separate software programs.

Available from: Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541

RODSTAR

Author: Theta Enterprises

Description: This Windows program provides modern design and simulation of rod pumping systems. RODSTAR enables the user to enter a "target" production and then automatically calculate the pumping speed, plunger size, and optimum rod string design best suited to the specified input. IPR integration allows RODSTAR to calculate the pump intake pressure from a target production or entered pumping speed. It can recommend the pumping unit or motor size needed and can simulate NEMA D or Ultra High Slip motors.

Available from:
Theta Enterprises
1211 W. Imperial Highway, Suite 105
Brea, CA 92821
Phone: (714) 526-8878
Fax: (714) 526-8875
Website: http://www.theta-ent.com

TESTBED

Author: Technical Application Software

Description: This test data analysis software allows the user to input data from test bay and produce a detailed technical specification and test curve. It includes customer details, pump information, test conditions, field ratings, and a wide range of graphing options. Customized test curves can be produced to both ISO and API standards. The output is compatible with GRAFTEC (TAS) for further analysis of data.

Available from:
Technical Application Software
PO Box 411203
2024 Craighall JHB
South Africa
Phone: +27 11 325 4813
Fax: +27 11 325 5312
Website: www.tassoftware.co.za/

VOLMATCHER

Author: Pump Technology Services

Description: Design parameters for both impeller and volute are input. Outputs include occurrence of BEP and head generated. This program is used in conjunction with PUMPAN to generate designs that take into account change of throat area, impeller outlet parameters, etc.

Available from:
Pump Technology Service
9 Pratt Court
Maddington 6109
Western Australia
Phone: (09) 493-3116
Fax: (09) 459-9541
E-Mail: pumptech@wantree.com.au

Training Courses

Centrifugal Pump Design and Performance

Description: This five-day course, offered by Concepts ETI, Inc., will inform students of centrifugal pump design principles and practice, including an appreciation of performance limits such as cavitation. It will help students to understand and assess design tools and understand the process of pump design optimization. Engineers will come to understand the best state-of-the-art design practices and learn about performance, cavitation, dynamic forces, and noise.

Available from: Concepts ETI, Inc. Headquarters
4 Billings Farm Road
White River Junction, VT 05001
Phone: (802) 296-2321
Fax: (802) 296-2325
E-Mail: CETI@VALLEY.NET
Website: http://www.conceptseti.com

Centrifugal Pump Vibration Analysis, Test, and Troubleshooting

Description: This two-day course focuses on discovering and solving pump mechanical problems. Topics include determination of .critical speed., natural deflection shapes and their importance to problem identification and solution; the influence of wear rings, balancing devices, and bearing types; lateral and torsional vibration; axial shuttling and resonance; acoustic resonance calculation and removal; special issues for vertical pumps; special issues for boiler feed and circulating water pumps; fast Fourier transform (FFT) equipment and practices; time averaged pulse .bump. testing; and practices in condition monitoring and condition-based maintenance.

Available from: Mechanical Solutions, Inc.
1719 Route 10 East, Suite 205
Parsippany, NJ 07054-4507
Phone: (973) 326-9920
Fax: (973) 326-9919
E-Mail: Msi@MechSol.com
Website: http://www.Mechsol.com

Centrifugal Pump Repair

Description: This course uses the comprehensive Activ[R] interactive multimedia training program to train users to understand, disassemble, inspect, troubleshoot, and repair centrifugal pumps. Designed for all levels of maintenance personnel as well as the training needs of process and manufacturing facilities, the four to eight hour training course is divided into two lessons (1) Principles and Troubleshooting and (2) Disassembly, Inspection, and Repair.

Available from: ITC Learning Corporation
13515 Dulles Technology Drive
Herndon, VA 22071-3416

Phone: (703) 638-3757
Fax: (703) 713-0065

Centrifugal Pumps

Description: Topics of this course (Course Number 119) include: operating characteristics and identification of parts of centrifugal pumps; flow-through pump; mechanical and packing seals; seal flush; parts of an impeller; identification of impellers; discharge pressure versus flow; power requirements versus flow; effect of specific gravity on power requirements; multistage operation; methods of priming centrifugal pumps; operating characteristics of self-priming centrifugal pumps; types of oil lubrication; grease-lubrication bearings; bearing housing temperatures; and cavitation and gassing of centrifugal pumps.

Available from: Job Training Systems, Inc.
P.O. Box 868
Unionville, PA 19375
Phone: (610) 444-0868
Fax: (610) 444-0684
Website: http://www.jobtraining.com

Energy Reduction in Pumps and Pumping Systems

Author: The Hydraulic Institute

Description: This one day short course, developed in conjunction with the U.S. Department of Energy Motor Challenge Program, demonstrates how to optimize pump system performance to achieve energy savings. This package includes a videotape of 60 minutes running time, and is intended for use with the accompanying workbooks. Topics covered include: designing a pumping system, evaluating performance characteristics, avoiding excessive capacity and total head margins, selecting the most efficient pump, using variable speed drives, maintaining pumps, using multiple pumps and power recovery turbines, and performing calculations for real energy savings. The course is intended for pump, engineering, and systems professionals. An instructor's manual and three participant workbooks and answer books are also included.

Available from: The Hydraulic Institute
9 Sylvan Way
Parsippany, NJ 07054
Phone: (888) 786-7744
Phone: (973) 267-7772
Fax: (201) 267-9055

FLO-SERIES Training Courses

Description: FLO-SERIES (see "Software" training classes.

Available from: Engineered Software Inc.
4531 Intelco Loop SE
Lacey, WA 98584-5941
Phone: (360) 412-0702
Fax: (360) 412-0672

E-Mail: sales@eng-software.com
Website: http://www.eng-software.com

Industrial Hydraulic Power

Description: This course includes five sections: Hydraulic System Operation; Hydraulic Pumps, Pumping Principles, and Accumulators; Pressure Controls; Directional and Flow Controls; and Hydraulic Actuators. Lesson 2 shows and explains the functions of pumps in hydraulic systems and the operating principles of different types of pumps. Common maintenance procedures performed on pumps, procedures for inspecting and monitoring pump efficiency, operating principles of different types of accumulators, common maintenance procedures, and precharging accumulators are also covered in this lesson. The entire course includes 10-20 hours of training and is designed for the training of mechanics, electricians, and operators as well as for the multi-craft training of process and manufacturing facilities.

Available from: ITC Learning Corporation
13515 Dulles Technology Drive
Herndon, VA 22071-3416
Phone: (703) 638-3757
Fax: (703) 713-0065

Mackay Pump School

Description: The Mackay Pump School is a two-day course covering the combined problems of system hydraulics, pump mechanics, and seal operation. The course is designed to help operations and maintenance personnel reduce production losses and downtime. Course topics include: pump and system curves, NPSH, cavitation, air entrainment, seal problems, shaft deflection, bearing considerations, and piping configurations. A video series from the Mackay Pump School is also available.

Available from: Ross Mackay Associates Ltd.
240 Portage Rd., Ste.670
Lewiston, NY, 14092
Phone: (800) 465-6260
Fax: (905) 936-4021
E-mail: rossmack@simcoe.igs.net

National Technology Transfer, Inc. Courses

Description: National Technology Transfer offers a wide variety of courses related to pumps and pump applications. From a two-day seminar on centrifugal pumps covering theory, selection, design, maintenance, and troubleshooting to a three-day Pneumatic Training course, National Technology Transfer offers courses nationwide for engineers, consultants, plant and maintenance personnel, and other interested in technical fields.

Available from: National Technology Transfer, Inc.
P.O. Box 4558
Englewood, CO 80155
Phone: (800) 922-2820
Fax: (303) 649-9930

Performance Optimization for Pump Systems: A Workshop for the Water/Wastewater Industry

Description: A one-day workshop covering the basics of pumping systems, energy use in pumping systems, and optimization of pump systems. The course includes a couple of case studies to help enable attendees to identify pumping optimization opportunities in their own plants.

Available from: Motor Challenge Information Clearinghouse
P.O. Box 43171
Olympia, WA 98504-3171
Phone: (800) 862-2086
Fax: (206) 586-8303
Website: http://www.motor.doe.gov

Performance Optimization Training

Description: This interactive two day course developed jointly by the Energy Center of Wisconsin and the DOE Motor Challenge Program covers the basics of optimizing new and existing pump, fan and blower systems. The course targeting plant engineers utilizes proven adult education principles to teach attendees to identify, quantify and prioritize optimization opportunities as well as how to build a business case for implementing optimization projects including quantifying energy benefits and identifying production and maintenance benefits. Specific sessions include: identifying opportunities; principles of operation; affinity laws; system response; effective system control; ASDs in fan and pump systems; using the right fan; using the right pump; and building the business case. The Energy Center of Wisconsin provides training and materials for end-users, utilities and consultants in Wisconsin and nationwide.

Available from: Energy Center of Wisconsin
595 Science Drive
Madison, Wisconsin 53705
Phone: (608) 238-4601
Fax: (608) 238-8733
E-mail: industrial@ecw.org
Website: http://www.ecw.org

Positive Displacement Pumps

Description: This course (Course Number 12) identifies reciprocating positive displacement pumps by type of power end, displacing solid, number of pumping units, type of pumping unit, and valve gear. In addition, the course identifies the common types of rotary positive displacement pumps by type of displacing solid. The operating principles of both types of pumps are applied to elementary troubleshooting.

Available from: Job Training Systems, Inc.
P.O. Box 868
Unionville, PA 19375
Phone: (610) 444-0868
Fax: (610) 444-0684

Website: http://www.jobtraining.com

Progressing Cavity Pumping Systems Design and Performance Optimization Short Course

Description: This comprehensive course has been developed to assist operators implementing progressing cavity (PC) pumping systems. The course focuses on the fundamentals, design, and operation of PC pumping systems for oil production. The course is based on knowledge and information acquired by C-FER since 1986 through field studies, lab investigations, and a major joint industry study focused on PC pumping system performance in a wide variety of production applications.

Available from: Eileen Charest
Phone: (403) 450-3300
Fax: (403) 450-3700
E-Mail: cfer@cfer.ualberta.ca

Pump Characteristics and Applications

Description: Standard and customized courses in pump sizing, system design, pump applications, troubleshooting, maintenance, and repair.

Available from: Volk & Associates
3062 Arizona Street
Oakland, CA 94602
Phone: (800) 733-8655
Fax: (510) 482-2839
E-mail: mvolk@aol.com

Reasons and Solutions for Misalignment in Centrifugal Pumps

Description: This two-day course examines the most common sources of misalignment, their root causes, and how to discover and permanently eliminate them. Topics include common causes and effects of misalignment; detecting problems by wear pattern, vibration and thermography; location and elimination of a .soft foot; avoiding excess nozzle loads due to thermal expansion; piping pressurization and pump nozzle/piping offset; large unexpected loads at poorly restrained expansion joints; thermal bow of hot casings during warm-up or operation; good alignment practices; and case histories filled with "dos and don'ts."

Available from: Mechanical Solutions, Inc.
1719 Route 10 East, Suite 205
Parsippany, NJ 07054-4507
Phone: (973) 326-9920
Fax: (973) 326-9919
Website: http://www.Mechsol.com

Rotating and Reciprocating Equipment

Description: Separate training programs are offered on Centrifugal Pumps and Positive Displacement Pumps. The Centrifugal Pump course (Title Code 2401) is an audio-visual workbook program covering the basics of centrifugal pump design and operation. Specific topics include centrifugal force, impeller and casting design, mechanical seals, bearings and lubrication systems, pressure and head, suction lift systems, net positive suction head, performance curves, pump priming, cavitation, start-up and shutdown procedures, and troubleshooting operating problems. The course includes 5 hours of training. An additional 7.5 hours of training is provided separately (Title Code 1071).

The Positive Displacement program (Title Code 1072) includes 14 hours of training in two sections. The program provides complete coverage of positive displacement pumps from introductory pumping fundamentals to the construction and use of these pumps in practical situations. Areas covered include rating of positive displacement pumps, performance characteristics, reciprocating pumps, rotary pumps, construction details, and operation.

Available from: American Petroleum Institute
P.O. Box 1327
Merrifield, VA 22116
Phone: (202) 682-8159
Fax: (202) 962-4776
Website: http://www.api.org

Understanding and Improving Rotordynamics in Centrifugal Pumps

Description: This two-day course addresses fundamental theory of rotordynamics; various methods of determining .critical speed.; natural frequency resonances of rotors; Lomakin Effect in wear rings and balance devices; rolling element vs. journal vs. tilting pad bearings; rotordynamic instability causes and cures; the influence of the stiffness and natural frequency of bearing housings; axial and torsional vibrations; vertical pump lineshaft or driveshaft behavior; low flow suction recirculation in boiler feed and circulation water pumps; and time average pulse testing to determine rotor natural frequencies and damping while the pump remains operating.

Available from: Mechanical Solutions, Inc.
1719 Route 10 East, Suite 205
Parsippany, NJ 07054-4507
Phone: (973) 326-9920
Fax: (973) 326-9919
E-Mail: Msi@MechSol.com
Website: http://www.Mechsol.com

On-Line Information

PROMT (Predicasts Overview of Markets and Technology)

Description: This on-line database includes companies, products, applied technologies, and markets for industrial products.

Available from: Information Access Company
362 Lakeside Dr.
Foster City, CA 94404
Phone: (800) 321-6388

Fax: (415) 358-4759

PumpNet Website

Description: This Website, produced by Price Pump, includes .PumpNet Interactive Pump Selection. which uses flow rate and head input from the user to provide the required duty. Also included is the Pump-Net Product Finder, one of the first on-line pump directories. This function allows the user to enter preferred pump type, application, drive type, material, and seal and returns a choice of manufacturers. There is also a .Free Online Pump School,. a one-hour course with lessons including, .What is a Centrifugal Pump?,. .Reading a Performance Curve,. .Cavitation and NPSH,. and "The Affinity Laws"

Available from: Website: http://www.pumpnet.com

Pump World Website

Description: Through the use of educational tutorials for centrifugal and positive displacement pumps, Pump World is dedicated to the advancement of the pump industry on the WWW. These tutorials include information on pump terminology and operation, performance curves, pump selection, troubleshooting, and preventative maintenance. Also included are pump application and system head/pressure forms for use by end users, pump distributors, and manufacturers.

Available from: Website: http://www.pumpworld.com/default.htm

Pump-Zone Website

Description: This website is maintained by Pump & Systems Magazine. This site includes: .Product Spotlights,. pump application data, feature articles, a software store, links to pump company websites, and all the current pump news.

Available from: Pump-Zone
Phone: (970) 221-2006
Fax: (970) 221-2019
Website: http://www.pump-zone.com/

Pumps & Filtration On-Line

Author: Process & Industrial Training Technologies, Inc.

Description: Internet magazine with articles, product listings and descriptions, and news regarding the pump industry.

Available from: Process & Industrial Training Technologies, Inc.
Phone: (513) 574-1666
Fax: (513) 574-1358
Website: http://www.iglou.com/pitt

Thomas Register of American Manufacturers

Description: A searchable on-line directory of manufacturers in a variety of industries. Participating companies can include product catalogs, on-line ordering information, and links to Websites. Also available in print.

Available from: Thomas Register of American Manufacturers

Thomas Publishing Company
Five Penn Plaza
New York, NY 10001
Phone: (800) 222-1900
Fax: (212) 290-7365
Website: http://www.thomasregister.com

U.S. Forecasts

Description: This on-line database includes abstracts of published forecasts relating to U.S. products, markets, and industries from 1971 to the present.

Available from: Information Access Company
362 Lakeside Dr.
Foster City, CA 94404
Phone: (800) 321-6388
Fax: (415) 358-4759

U.S. Time Series

Description: This on-line version of the "Predicasts Basebook" includes annual times series of historical data with government and private sources of information on the U.S. economy, products, and industries. The series begins in 1957 and runs through the present.

Available from: Information Access Company
362 Lakeside Dr.
Foster City, CA 94404
Phone: (800) 321-6388
Fax: (415) 358-4759

New York, NY 10001
Phone: (800) 222-1900
Fax: (212) 290-7365
Website: http://www.thomasregister.com

U.S. Forecasts

Description: This on-line database includes abstracts of published forecasts relating to U.S. products, markets, and industries from 1971 to the present.

Available from: Information Access Company
362 Lakeside Dr.
Foster City, CA 94404
Phone: (800) 321-6388
Fax: (415) 358-4759

U.S. Time Series

Description: This on-line version of the "Predicasts Basebook" includes annual times series of historical data with government and private sources of information on the U.S. economy, products, and industries. The series begins in 1957 and runs through the present.

Available from: Information Access Company
362 Lakeside Dr.
Foster City, CA 94404
Phone: (800) 321-6388
Fax: (415) 358-4759

APPENDICES

Table of Contents

APPENDIX A

GLOSSARY OF BASIC TERMINOLOGY

Absolute Pressure - Total force per unit area in a system (includes vapor pressure and atmospheric pressure).

Adjustable Speed Drives (ASDs)* - Devices that allow control of a pump's rotational speed. ASDs include mechanical devices such as hydraulic clutches and electronic devices such as eddy current clutches and variable frequency drives.

Affinity Laws - A set of relationships that tie together pump performance characteristics such as pressure, flow, and pump speed.

Backpressure - The pressure on the discharge side of the pump.

Bearing - A device that supports a rotating shaft, allowing it to spin while keeping it from translating in the radial direction. A thrust bearing keeps a shaft from translating in the axial direction.

Best Efficiency Point (BEP) - Commonly used to describe the point at which a centrifugal pump is operating at its highest efficiency, transferring energy from the prime mover to the system fluid with the least amount of losses.

Brake Horsepower (bhp) - The amount of power (measured in units of horsepower) delivered to the shaft of a driven piece of equipment.

Cavitation - A phenomenon commonly found in centrifugal pumps in which the system pressure is less than the vapor pressure of the fluid, causing the formation and violent collapse of tiny vapor bubbles.

Centrifugal Pump - A pump that relies on a rotating, vaned disk attached to a driven shaft. The disk increases fluid velocity, which translates to increased pressure.

Check Valve - A valve that allows fluid to flow in one direction only; generally used to maintain header pressure and protect equipment from reverse flow.

Deadhead - A condition in which all the discharge from a pump is closed off.

Dynamic Head - The component of the total head that is attributable to fluid motion (also known as velocity head).

Gauge Pressure - Measure of the force per unit area using atmospheric pressure as the zero reference.

*Terms in Blue Bold are linked to Section 1: Introduction to Pumping Systems

Head - A measure of pressure (expressed in feet) indicating the height of a column of system fluid that has an equivalent amount of potential energy.

Header - A run of pipe that either supplies fluid to (supply header), or returns fluid from (return header), a number of system branches.

Heat Exchanger - A device that transfers heat from one fluid to another.

Horsepower - Measure of the work or energy flux per unit time; the rate at which energy is consumed or generated.

Impeller - A centrifugal pump component that rotates on the pump shaft and increases the pressure on a fluid by adding kinetic energy.

Kinetic Energy - The component of energy that is due to fluid motion.

Load Factor - A ratio of the average capacity to the rated full capacity, determined by the following relationship:

$$\text{Load Factor} = \frac{\sum \text{(Actual Load x Number of operating hours at this load)}}{\text{Rated Full Load x Number of hours in the period}}$$

Mechanical Seal - A mechanical device for sealing the pump/shaft interface (as opposed to packing).

Minimum Flow Requirement - A manufacturer-specified limit that represents the lowest flow rate at which the pump can operate without risking damage from suction or discharge recirculation.

Motor - An electric machine that uses either alternating current (AC) or direct current (DC) electricity to spin a shaft. Typically, this shaft is coupled to a pump. Occasionally, however, mechanisms such as a slider/crank convert this rotation to axial movement to power piston pumps.

Motor Controller - An electric switchbox that energizes and de-energizes an electric motor.

Packing - A form of a pump seal that prevents or minimizes leakage from the pump stuffing box. Packing is usually a flexible, self-lubricated material that fits around the pump shaft, allowing it to spin while minimizing the escape of system fluid between the shaft and the pump housing.

Performance Curve - A curve that plots the relationship between flow and head for a centrifugal pump. The vertical axis contains the values of head while the horizontal axis contains flow rates. Since flow rate varies with head in a centrifugal pump, performance curves are used to select pumps that meet the needs of a system.

Pony Pump - A pump that is usually associated with a larger pump in a multiple-pump configuration. The pony pump typically handles normal system requirements, while the larger pump is used during high demand periods.

Positive Displacement Pump - A pump that pressurizes a fluid using a collapsing volume action. Examples include piston pumps, rotary screw pumps, and diaphragm pumps.

Pressure - Force per unit area. Commonly used as an indicator of fluid energy in a pumping system (expressed in pounds per square inch).

Prime Mover - A machine, usually an electric motor, that provides the motive force driving a pump.

Recirculation - A flow condition which occurs during periods of low flow, usually below the minimum flow requirement of a pump. This condition causes cavitation-like damage, usually to the pressure side of an impeller vane.

Relief Valve - A valve that prevents excessive pressure buildup. Often used on the discharge side of a positive displacement pump and in applications where thermal expansion of a system fluid can damage system equipment.

Specific Gravity - The ratio of the density of a fluid to the density of water at standard conditions.

Specific Speed - An index used to measure the performance of an impeller. Represents the speed required for an impeller to pump one gallon per minute against one foot of head. Defined by:

$$N_s = \frac{n_s \sqrt{Q}}{H^{3/4}}$$

Static Head - The head component attributable to the static pressure of the fluid.

Stuffing Box - The part of a pump where the shaft penetrates the pump casing.

Suction Specific Speed - An index used to describe the inlet conditions of a pump. Defined by the equation:

$$S = \frac{n_s \sqrt{Q}}{NPSHR^{3/4}}$$

Total Head - A measure of the total energy imparted to the fluid by a centrifugal pump. This value includes static pressure increase and velocity head.

Valve - A device used to control fluid flow in a piping system. There are many types of valves with different flow control characteristics, sealing effectiveness, and reliability.

Valve Seat - The component of a valve that provides the sealing surface. Some valves have just one seat while others have a primary seat, which prevents leakage across the valve, and a back seat, which prevents leakage from the valve to the environment.

Vapor Pressure - The force per unit area that the fluid exerts in an effort to phase change from a liquid to a vapor. This pressure is a function of a fluid's chemical and physical properties, and its temperature.

Variable Frequency Drives (VFD) - A type of adjustable speed drive that controls the speed of ac motors by regulating the frequency of the electric power. VFDs are the most common type of adjustable speed drives and can achieve significant reductions in energy use by matching the speed of driven equipment to required output.

Velocity Head - The component of the total head that is attributable to fluid motion (also known as dynamic head).

Viscosity - The resistance of a fluid to flow when subjected to shear stress.

APPENDIX B

THE PUMP SYSTEM MARKETPLACE

The pump marketplace is complex due to the wide range of pumping applications. Pumps serve residential, commercial, municipal, agricultural, and industrial fluid system needs, and are sold to these different markets through different channels. Customer sophistication, system application, and pump cost are among the principal factors that affect the marketing of pumps. Since industrial applications represent the largest pump market, this segment will be the primary focus of this *Sourcebook*.

Market Size and Energy Consumption

In 1995, more than 6.7 million industrial pumps were sold in the US, valued at almost $2.7 billion. There are two basic types of pumps -- centrifugal and positive displacement. Centrifugal pumps lead the process industries in terms of annual unit sales, capacity, and total electricity consumption. Centrifugal pumps are reliable, have characteristically long operating lives and low maintenance requirements. Positive displacement pumps, on the other hand, are used in special applications, such as those requiring high pressures, metered flow, or high viscosity fluids.

Pumps are responsible for 27 percent of all motor-driven industrial electricity consumption in the United States. The 21-125 horsepower (hp) class is the largest segment of the pump market, accounting for more than half of all pump sales. Pumps that are 20 hp or less are typically sold in packages that include the pump, drive train, and motor. Pumps of more than 50 hp are typically sold as units, separate from the motor, drive train, and controls.

Market Distribution Channels

While manufacturers can sell pumps directly to pump users, distributors, dealers, and manufacturers' representatives are the primary go-to-market channels. Due to the wide range of applications and varying degrees of pump user needs, the pump marketplace is relatively complex (see Figure 1). The key points of influence for promoting market transformation in the process pump systems market are:

- Pump manufacturers and their internal sales staffs,
- Pump distributors,
- Manufacturers' representatives,
- Engineering/design firms, and
- Pump users.

Pump Manufacturers

Pump manufacturers design and produce pumps. Manufacturers have widely varying corporate structures and go-to-market strategies. Manufacturers also devote engineering and product support resources differently, according to the markets they serve. For example, cooling water pumps for HVAC systems are fairly common and do not see harsh service requirements; manufacturers that specialize in these types of pumps treat these products like commodities, devoting comparatively little resources to research and development and after-sales support. The profit margins in these lowtech applications tend to be small. In contrast, manufacturers that specialize in highly abrasive and corrosive fluid environments expect higher profit margins and lower unit sales, but typically spend comparatively large amounts of resources on materials research and customer service. Some manufacturers are diversified, serving both commodity and specialized markets.

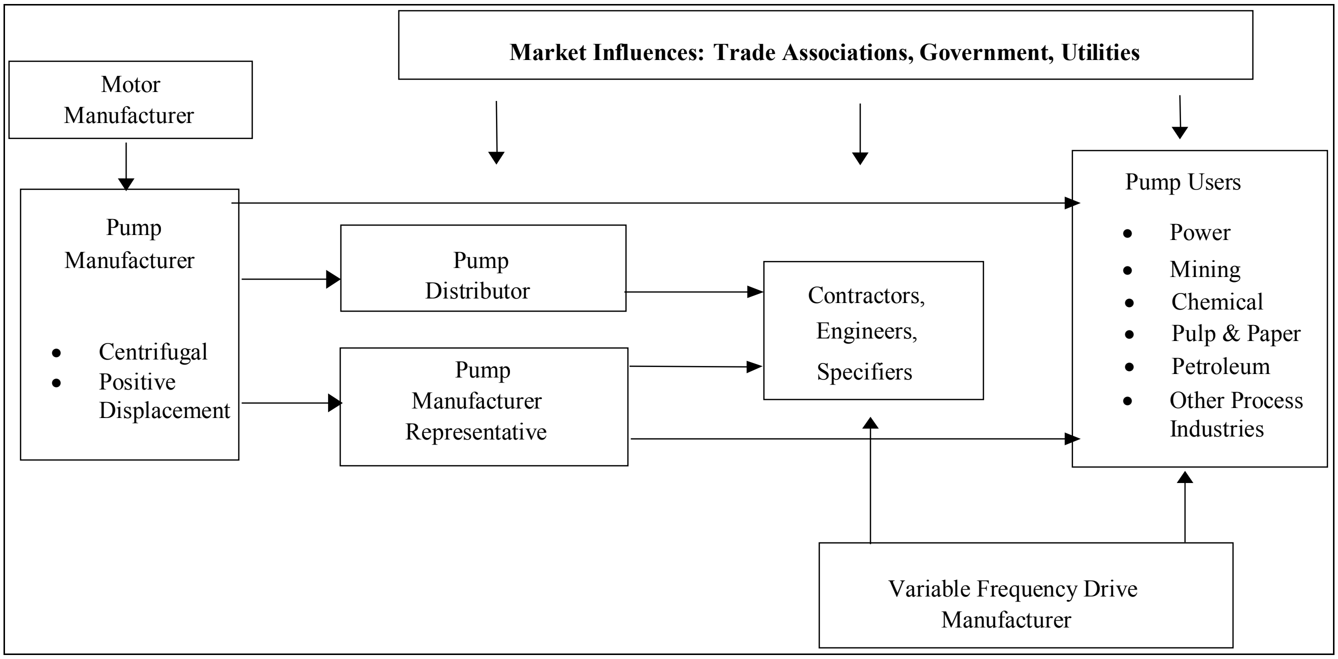

Figure 1 The Pump Marketplace

A relatively small number of manufacturers dominate the U.S. process pump market. The two largest process pump manufacturers account for more than half of all pump sales to the process industries. Rather than focusing on specific industries as do many pump manufacturers the two largest manufacturers produce both general-purpose pumps and products for specific industries.

Manufacturers do not typically provide complete system design services to pump customers (except when the application is highly demanding and involves an unusually high revenue opportunity). Most pump sales and service support is provided by distributors, dealers, and manufacturers' representatives. This market structure has exceptions, since some manufacturers offer direct sales to pump users. In the case of direct pump-user sales, manufacturers benefit from increased profit margins while the customer may benefit from slightly lower prices. This relationship can force the pump user to contend with poor after-sales service, however, which exposes the manufacturer to the risk of lost repeat sales.

Pump Distributors, Manufacturer Representatives, and Dealers

Pump distributors, manufacturers' representatives, and dealers are the primary links between the manufacturer and pump user. These links are a major part of the go-to-market strategy of the pump manufacturer. This strategy depends heavily on the application the pumps are primarily designed for, and the level of customer sophistication.

Dealers tend to be geographically oriented and are used in many commodity market applications such as residential dewatering pumps. Dealers are often plumbing supply companies that provide contractors with a number of goods, such as pipe fittings, welding equipment, and pumps. The dealers themselves are supplied by distributors. Dealers are usually not required to exclusively sell one manufacturer's pumps, although there are exceptions.

In this market structure, both the dealer and the distributor take possession of the pumps from the manufacturer and are subsequently exposed to inventory costs and sales risk. Their profit margins reflect the administrative responsibilities of selling and collecting payment, as well as assuming the risk that a pump will be sold from inventory.

Distributors, in contrast to dealers, tend to supply a more specific line of goods, such as pumps and ancillary products that directly support pumps. Distributors also tend to carry the pumps from one manufacturer. In some market segments, distributors do not need the dealer to provide the customer interface and engage in direct sales themselves. These market segments usually involve higher-end pumps that are more expensive and have higher profit margins. Again, the distributor buys pumps from the manufacturer, stocking an inventory and taking the risk that accompany making sales and collecting payments.

Manufacturer representatives perform a market function that is similar to that of distributors, in terms of providing direct customer contact. Manufacturer representatives tend to specialize in specific market areas, providing preliminary project budgetary pricing and technical support to customers. Manufacturer representatives also assist customers in setting up spare parts inventories, and determining maintenance schedules and, if necessary, arranging for personnel training. Manufacturer representatives do not take possession of the pumps, however, and are not exposed to the risk of sales. Manufacturer representatives place orders for sales and the manufacturer ships the unit directly to the pump customer.

The essential differences between manufacturer representatives and distributors are in the areas of customer service and after-sales support. Distributors are usually required by the manufacturer to carry a certain inventory of pumps and spare parts and typically offer repair services. Distributors are able to ship pumps to the customer more quickly and can readily access replacement parts. Although manufacturer representatives provide customer support, they usually do not stock an inventory and often must coordinate with the manufacturer for replacement parts. With manufacturer representatives, the time from order placement to pump delivery is also typically longer.

Both manufacturer representatives and distributors understand the performance characteristics of their lines of pumps. They will often work with customers in selecting the appropriate pump sizes and motor types for a given application. Dealers often rely on the pump customer to select the most suitable pump model.

Contractors/Engineers/Specifiers

Contractor and engineering firms often handle turnkey production facility design, including system design, pump sizing, and pump selection. New pumping systems, in addition to replacement pumps sold to pump users, are typically installed by mechanical contractors. Consulting engineers provide design services and help specify equipment for new facilities as well as major retrofits and system renovations.

The role of specifying engineers is to design a system and select the pumps that meet the system's needs. These engineers must ensure the system meets the needs of the application; however, once the system is installed and operating, the specifying engineers' task is complete. Since operating and maintenance costs are future costs, not applied to the capital budget, there is a tendency to focus on initial system performance certification. This practice often results in equipment that is slightly oversized. The constraint against sourcing significantly oversized equipment is the higher cost associated with larger equipment rather than the need to keep life cycle costs down.

Pump Users

Pump users vary in the methods they use to identify and select pumps. Large, sophisticated pump users often use an in-house engineering staff to design systems and source system equipment such as pumps, motors, and control systems. Other pump users utilize local distributors or manufacturers' representatives to help select the best pump for an application.

Whether keeping pump specifying tasks in-house or use specifying engineers, pump users evaluate proposed systems using initial cost, performance, reliability, and life-cycle cost as the criteria. The balance among these criteria changes according to the sophistication level of the pump user, the needs of the application, and resource constraints.

In many applications, system downtime is highly expensive, and with this threat in mind, pump systems are designed conservatively which often promotes pump oversizing. The costs of oversizing pumps are considered small relative to the cost of restricting system capacity due to insufficient pump output. This perception overlooks the impact on reliability of operating a pump below its best efficiency point (BEP), however. Oversizing a pump is different than oversizing a pipe wall thickness or decreasing the distance between pipe supports in that long-term reliability is sacrificed rather than improved.

Some pump users are sufficiently knowledgeable about pump system operation to know the problems associated with poor system design practices. Many pump users do not realize the penalties of inefficient pump operation, however. Pump manufacturers, dealers, distributors, manufacturer representatives, and specifying engineers are stakeholders in initial pump performance; but the pump user alone pays for the long-term operating and maintenance costs of running the pump.

Standards and Trade Associations

Trade associations, government entities, and electric utilities also play vital roles in the process pump market. Three trade associations are key players in the pump industry:

- ### Hydraulic Institute (HI)

HI is a North American non-profit industry association for manufacturers of pumps and pump systems, promoting the effective, efficient, and economic use of pumps and pump products worldwide. By developing standards that define and control the performance, testing, life, and quality of pumps and pump products, HI helps eliminate misunderstandings between manufacturers, purchasers, and pump users. These voluntary standards help the purchaser to select and obtain the pump best suited to a particular need. All HI standards are developed in accordance with ANSI guidelines. HI is also a source for other pump-related publications and educational products.

HI has recently established a Life Cycle Cost Committee to focus industry attention on opportunities for pumping system improvements that will lead to reduced total cost of ownership for pumping systems. This committee plans to prepare materials that will present the life cycle cost concept to specifiers, manufacturers, distributors, owners, and users of pump systems. The committee is developing a method of calculating life cycle cost that will include design, procurement, installation, operation, maintenance, repair, decommissioning and disposal of pump systems. The committee also plans to adopt or develop tools that will allow the life cycle cost of alternative pump systems to be compared on a consistent basis. This committee is cooperating with EUROPUMP, a European pump manufacturers trade association, in a similar effort, the "Enersave" program, for the European community. To contact HI, see the Directory of Contacts.

- American National Standards Institute (ANSI)

ANSI is a private, non-profit membership organization whose goal is the administration and coordination of standards for a broad range of goods and services. This organization is made up of manufacturers and industry professionals. ANSI is the sole U.S. representative to the International Organization for Standards (ISO) and the International Electrotechnical Commission (IEC). The purpose of standards organizations is to promote uniformity. This uniformity provides a valuable interchangeability among the products of different manufacturers, allowing a burned-out light bulb to be replaced with a light bulb from any manufacturer, for example. This interchangeability allows plants to maintain standard parts inventories rather than keep special replacement items for each piece of equipment.

With respect to pumps, ANSI maintains a number of codes developed by the Hydraulic Institute and other organizations. There are ANSI codes for centrifugal pumps, positive displacement pumps, and fire-protection pumps. Most of these codes, however, are relatively general and do not require specific performance criteria. As an exception, the ANSI chemical process pump specifies pump design, performance criteria, and many critical dimensions such as shaft size, and suction and discharge pipe flange patterns. This ANSI standard was developed in response to the need by chemical plant operators to facilitate maintenance and repair efforts. Since chemical plants tend to operate hundreds of pumps, storing replacement parts for each different pump was prohibitively difficult. Under ANSI direction, a class of pump was standardized, offering a common benefit for the whole industry. To contact ANSI, see the Directory of Contacts.

- American Petroleum Institute (API)

Similar to ANSI, API is a trade association consisting of exploration and production, transportation, refining, and marketing organizations from the petroleum industry. The API has developed a standard for pumps in petroleum applications. Unlike the ANSI chemical process pump standard (which specifies dimensions) the API standard addresses the aspects of pump design that are more ring clearances, and material requirements. To contact API, see the Directory of Contacts.

Engineering Societies

Engineering societies can be useful in resolving pumping system problems by referring to resources or publications that describe how other pump users have resolved similar problems. Two such societies are:

- The Society of Tribologists and Lubrication Engineers (STLE) focuses on issues of wear and machine reliability which translates to an interest in predicting and avoiding failures in bearings and mechanical seals. Pump users that experience bearing or seal problems may benefit from the STLE's knowledge of lubrication, material selection, and predictive analysis. To contact STLE, see the Directory of Contacts.

- The American Society of Mechanical Engineers (ASME) has interest in the design and operation of machines and components. ASME reports on technology developments that can impact material selection and pump design. To contact ASME, see the Directory of Contacts.

APPENDIX C

PRESCREENING MOTOR SYSTEMS FOR POTENTIAL ENERGY SAVINGS - GENERIC CONSIDERATIONS -

This appendix provides guidelines, checklists and sample data collection sheets that pump users can reference when seeking to identify potential energy efficiency improvements. The checklist and data collection forms can be photocopied for use by pump system end users.

This prescreening tool was developed by Oak Ridge National Laboratory for the Motor Challenge program. It is meant to identify likely candidate pump systems for further engineering review. It is not intended to identify specific solutions, but to help the end user locate opportunities for energy efficiency improvements.

BEFORE SCREENING

For any motor driven device (or any energy user, for that matter), the first question asked should be:

CAN IT BE TURNED OFF?

This should not only be the first question that is asked, but it should be asked frequently, and at each level of review. This is an action with a guaranteed savings percentage . 100%. Although simplistic, it is an amazingly common action, particularly in systems with multiple, parallel pieces of equipment.

This discussion provides a general approach and some guidelines for identifying and prioritizing candidates for energy reduction opportunities in motor-driven systems. It does not address non-motor system energy usage. It focuses primarily on fluid pumping systems, although the first selection criterion is general in nature.

The intended use is as a prescreening tool, particularly for motor users who are not familiar with the energy-related aspects of pumping systems. It cannot identify solutions or even pinpoint pumping systems where guaranteed savings are feasible. It *can* be used to develop a list of likely candidates. Pumps and systems identified with this prescreening tool will require further engineering review to determine the actual potential for savings and to identify alternative methods of achieving those savings.

I. PRIMARY SCREENING

A. FILTER BY COMPONENT SIZE AND OPERATING TIME

Classify the systems by motor size and estimated annual service hours, and calculate the product of the motor rated power and the annual operating hours (see Table 1 for an example).

Select a portion of the systems for more careful examination based primarily, but not exclusively, on the product of the motor size and service hours. Other factors that should be considered include the system complexity and interrelated systems. Relatively simple systems can be more quickly assessed and corrected if necessary, resulting in a reduced payback exclusively, on the product of the motor size and service hours. Other factors that should be considered include the system complexity and interrelated systems. Relatively simple systems can be more quickly assessed and corrected if necessary, resulting in a reduced payback period. Where there are interrelated systems (such as a chilled water system with the attendant chiller compressor, chilled water pumps, tower water pumps and cooling tower fans) they should be addressed concurrently, and not simply segregated by size, since changes made to one system may have an impact on related systems.

Table 1. Example Prioritization Summary

System	Device Name/ID	Rated HP	Annual operating hours	1000's HP-hrs
Chilled Water	Pump CW101	10	8760	88
Aeration	Fan S227	50	8760	438
Compressed air	Compressor	450	6000	2700
Boiler feed	Pump FW16	100	8000	800
Waste treatment	Transfer pump	75	4000	300

Note: the 1000's HP-hrs is the product of the rated hp and annual operating hours; it is not a true estimate of energy consumption, since at this survey level, the actual motor load is not known.

The primary screening filter is a very simple approach. There is no definite criterion for what fraction of the systems at a particular facility require further review. Keep in mind that the level of effort should be proportional to the size of the potential reward. As an extreme example: it might literally take several years to recover the cost of having an engineer or technician spending just a day searching for pump performance curves, analyzing measuring system conditions, and investigating more efficient alternatives on a 5-hp pumping system. Of course, if there are only 5-hp systems in your facility and many are similar, the effort might be worthwhile. The table in Attachment 1 shows some example savings for a variety of loads, costs, and efficiency improvements. It is useful to spend a minute reviewing Attachment 1 to get a feel for the kinds of savings afforded by energy efficiency improvements.

B. SCREENING BY LOAD TYPE

The type of load driven by motors is an important factor in prioritization. Current generation motors are very efficient devices, particularly when operated above 40% of their rated load. The motor-driven devices and the systems where the devices are used are normally the prime opportunities for energy savings. Generally speaking, fluid handling components and systems, such as pumps and fans and the systems they serve, are the most likely candidates for efficiency improvement.

After identifying pumping systems for further consideration in the generic screening activity described above, there are two general approaches to take. One approach involves looking for symptoms. The other involves acquiring and analyzing data. These two approaches are complementary, and both should be used when possible. Even when one is committed to the more rigorous data acquisition and analysis method, the value of simply being around the operating equipment and the people that operate it cannot be overstated. Some specific features associated with these approaches are described below.

II. SECONDARY SCREENING — SYMPTOMS

Generally speaking, looking for symptoms involves *walking down* the system, talking with operators to find out how the system is operated (and how operation varies with time), and generally using the human senses (sight, sound, touch, smell) to observe indications of waste energy.

The following are common symptoms that at least suggest the potential for energy savings. In many cases, these symptoms may also indicate a likelihood of reliability improvement opportunities.

A: LOOK FOR:

1. Systems with throttled flow control, particularly with significantly throttled valves[1],
2. Systems which employ normally open bypass lines for flow control or pump minimum flow protection (unless the minimum flow protection bypass flow is known to be small - e.g., less than 5% of the normal flow rate),
3. Systems with multiple parallel pumps for which the number of operating pumps is seldom changed,
4. A system that operates in a batch or cyclical start/stop mode where the pump cycles frequently (i.e., many starts and stops), and
5. The presence of significant cavitation noise either at the pump or in the system (such as at a throttled valve). Cavitation, at low levels, sounds like gravel is being pumped through the system. At high levels, it is more like a raspy roar and is very unpleasant to be around without hearing protection.

B: OTHER FEATURES TO NOTE:

Consider the nature of the system. If it is obvious that the *required* flow rate *should* change significantly over time (for example, chilled water pump flow requirements should vary significantly between winter and summer), a single pump would not likely be suited to the wide range of flow rate. Unless the pump uses a variable speed drive (see discussion on variable speed drives at the end of this article), further consideration of the pump application should be given.

Another factor to consider is whether the requirements for the system have evolved and changed over time. In many older systems, particularly in industrial process facilities, systems may serve significantly different functions or see dramatically different loads than what they were originally designed to meet. Such systems are certainly candidates for further review.

III. SECONDARY SCREENING - ACQUIRING, ANALYZING DATA

The acquisition and analysis of data is a more disciplined, and hopefully more accurate and quantifiable approach. Within this approach, there are opportunities for multiple levels of activity. Ideally, the energy input into the system and the useful work done by the system would be measured and an overall efficiency or measure of effectiveness developed. To that end, a Pumping System Assessment Tool (software), currently under development by the Motor Challenge Program, will

[1] Particularly note systems where globe-style control valves are used and are significantly smaller than the adjacent piping. Even if the valve is full open, the frictional losses can be substantial.

greatly simplify the identification of savings opportunities in pumping systems. However, there are some relatively simple measurements and analysis actions that can be done with pencil and paper (a calculator is helpful).

It should be noted that at a good fundamental understanding of pumping system parameters like flow rate and head are needed to undertake this effort, including a familiarity with pump and system performance curves. The Motor Challenge Program offers workshops on pumping system optimization that cover the necessary information.

There are two general sources of inefficiency in pumping systems:

1. An imbalance between the system requirements and actual conditions (or between needs and supply), and
2. Operation of the pump at an inefficient point.

These two categories are individually discussed below. It is important to note that they can co-exist (i.e., there is an imbalance between needs and supply *and* the pump is operating at an inefficient condition). However, one can also exist without the other (e.g., a pump operates at its best efficiency point, but provides twice as much flow as the system needs).

A. LOOKING FOR AN IMBALANCE IN REQUIREMENTS AND ACTUAL CONDITIONS

To do a useful assessment of the pumping system, there are two fundamental parameters that must be known - the flow rate and head. In addition, it is important to distinguish between the *required* system flow rate and head and what *actually exists*. It is often the case that more flow and/or more head are being developed than are truly needed. Excess in either area directly translates into excess energy consumption. Obviously, if you are to discern whether there is a difference in what is required and what actually exists, you must:

1. Understand the purpose and ultimate goal of the system, and
2. Be able to take necessary measurements to determine what actually exists.

By gathering this information and using the imbalance procedure identified in Table 2, an indication of energy savings opportunities will begin to emerge. Table 2 shows examples of imbalance between system requirements and actual pump conditions. For this example table, if there is an imbalance between requirements and measured conditions exceeding 20%, the system is marked for further review.[2] Note that there are two entries for chilled water, which reflect different system conditions (e.g., summer vs. winter). For the higher flow rate requirement condition (1400 gpm), the system requirements and actual operating conditions are reasonably balanced, but at the low flow rate (800 gpm), there is considerable imbalance. This illustrates the importance of clearly distinguishing different modes of system operation which can, of course, vary by the time of day, week, or month as well as year.

[2] The value of 20% as a mismatch threshold is somewhat arbitrary. The important thing is to record the level of imbalance, and use this as *one* of the factors in prioritizing the systems needing further investigation.

Table 2. Imbalance Example

Type of Water System	Required system (GPM)	Required system head (FT)	Measured pump (GPM)	Measured pump head (FT)	Imbalance (%)	Further review?
Chilled water	800	45	800	70	56	Yes
Chilled water	1400	55	1400	60	9	No
Tower water	1200	40	2000	50	108	Yes
Demin water	2000	110	2200	115	15	No

$$\text{Imbalance (\%)} = \left(\frac{\text{Measured Flow Rate} \times \text{Measured Head}}{\text{Required Flow Rate} \times \text{Required Head}} - 1 \right) \times 100\,\%$$

B. LOOKING FOR AN IMPROPERLY SIZED PUMP

An improperly sized pump often accompanies an imbalance between required and actual system conditions, although the two can also exist independently. To make a determination of whether a pump is properly sized or not, it is necessary to measure or estimate the existing operating condition and compare it to the pump design condition. There is one flow rate where the pump is most efficient, called the best efficiency point (BEP). The further the actual pump flow rate is away from the BEP, the greater the efficiency loss. Unlike motors, for which the efficiency varies little across a wide range of operation (there is typically less than a 2% variation in motor efficiency across the range of 40-100% of rated load), the pump efficiency is strongly affected by flow rate.

For systems with measurable pump flow rate, compare the measured flow rate with the pump BEP flow rate. The BEP flow rate can be determined from the pump performance curves. If the pump performance curve is not available and the BEP flow rate is unknown, but there is a nameplate flow rate on the pump, use that flow rate as a reference. Pumps that are operating more than 30% away from the BEP (or nameplate) flow rate should be included in the group for further analysis.

If the pump flow rate is not measurable, but pressure is, use the pump performance curve[3] to estimate flow rate. Alternatively, if a batch process is involved, deduce flow rates by observing level changes in a tank or reservoir over time. After estimating the flow rate, make the comparison discussed in item 1 above.

If a pump performance curve is not available, but the pump nameplate flow and head values are, a cruder indication can be developed if only the pump head can be measured. If the measured head is more than 20% away from the nameplate value, further analysis is warranted. It is important to note that there is much more uncertainty in comparing head values than flow rates, so this should be a last resort.

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[3] If a pump performance curve is not available, ask the pump vendor for one, or consider having a field performance curve developed, particularly if the pump is a large energy user. The availability of performance curves is a critical part of any effort to optimize pumping systems.

IV. SPECIAL CONSIDERATION — VARIABLE SPEED DRIVES

Variable speed drives applied to pumps can be very helpful in reducing energy consumption. In systems where the flow rate varies with time, and the head for the system is mostly frictional, a variable speed drive is an excellent solution. However, the simple existence of a variable speed drive does not guarantee optimization. Some situations in variable speed driven systems that suggest further review would be worthwhile include:

1. A variable speed drive used in a system for which most of the system head is static (i.e., due to an elevation or ambient pressure change),
2. A system which has been retrofitted with a variable speed drive but which still has high pressure drop control valves (e.g., globe valves) installed, or
3. Older variable speed drives such as eddy current devices or wound rotor motors routinely operated at significantly reduced speeds (that is, low as a fraction of the rated speed).

Attachment 1

Example savings, cost and simple investment return periods

Operational change only Design and operational changes

Power required, kwe	Typical motor hp	Annual operating hours	Annual cost ($) at 5 cents/kwhr	Annual savings for 10% improvement	One day of engineering labor	10% simple payback period, years	Annual savings for 40% improvement	5 days of engineering, craft labor	Simulated equipment cost	40% simple payback period, years
3	5	2000	$300	$30	$700	23.33	$120	$3,500	$600	34.17
3	5	4000	$600	$60	$700	11.67	$240	$3,500	$600	17.08
3	5	6000	$900	$90	$700	7.78	$360	$3,500	$600	11.39
3	5	8000	$1,200	$120	$700	5.83	$480	$3,500	$600	8.54
7	10	2000	$700	$70	$700	10.00	$280	$3,500	$1,000	16.07
7	10	4000	$1,400	$140	$700	5.00	$560	$3,500	$1,000	8.04
7	10	6000	$2,100	$210	$700	3.33	$840	$3,500	$1,000	5.36
7	10	8000	$2,800	$280	$700	2.50	$1,120	$3,500	$1,000	4.02
10	15	2000	$1,000	$100	$700	7.00	$400	$3,500	$1,400	12.25
10	15	4000	$2,000	$200	$700	3.50	$800	$3,500	$1,400	6.13
10	15	6000	$3,000	$300	$700	2.33	$1,200	$3,500	$1,400	4.08
10	15	8000	$4,000	$400	$700	1.75	$1,600	$3,500	$1,400	3.06
70	100	2000	$7,000	$700	$700	1.00	$2,800	$3,500	$8,000	4.11
70	100	4000	$14,000	$1,400	$700	0.50	$5,600	$3,500	$8,000	2.05
70	100	6000	$21,000	$2,100	$700	0.33	$8,400	$3,500	$8,000	1.37
70	100	8000	$28,000	$2,800	$700	0.25	$11,200	$3,500	$8,000	1.03
200	300	1000	$10,000	$1,000	$700	0.70	$4,000	$3,500	$18,000	5.38
200	300	2000	$20,000	$2,000	$700	0.35	$8,000	$3,500	$18,000	2.69
200	300	4000	$40,000	$4,000	$700	0.18	$16,000	$3,500	$18,000	1.34
200	300	6000	$60,000	$6,000	$700	0.12	$24,000	$3,500	$18,000	0.90
200	300	8000	$80,000	$8,000	$700	0.09	$32,000	$3,500	$18,000	0.67

Explanation and discussion

The example values used above are to help provide a general idea only. Clearly, there are several variables involved in determining costs, savings, and payback periods. The simple payback period is calculated as follows:

$$\text{Simple payback period} = \frac{\text{labor + equipment costs}}{\text{annual savings}} = \frac{\text{labor + equipment costs}}{(\text{kW}_e \text{ x annual operating hours x electricity cost (cents/kWh) x percentage savings/100)}}$$

The general concept of the table on Attachment 1 is to illustrate the relative costs of labor and materials and the combined impact on the payback period. The important points to be drawn from the table are:

1. It is very difficult to cost justify expending significant effort on investigating operational changes in small equipment, even when it runs most of the time. For example, in the case of a 200 kwe load (300 hp motor) which only runs 1000 hours per year (less than three hours a day), the cost of a day of engineering review spent to develop a 10% savings would only take about 4 months to recover. It would take more than 8 times as long to recover the cost of the engineer-for-a-day if a similar percentage improvement were made for the 3 kwe load (5 hp motor) *that runs more than 90% of the time*.
2. It is even more difficult to cost justify design and equipment changes in small motor systems. While there certainly may be some changes that can be made with less expense than the values assumed in the table, the values shown are not atypical.

In summary, efforts should obviously be structured to start with the largest equipment first. There is not only a greater likelihood of finding cost effective opportunities, but the energy savings will be more clearly detectable in the overall cost of doing business. From a practical standpoint, this can be very important in justifying similar efforts on other equipment and facilities.

FORMS

Tabular and checklist style forms are included on the following pages. These forms may be useful in performing primary prescreening and pumping system secondary prescreening activities consistent with the guidelines described in this discussion.

Pump system energy opportunity screening
-Symptoms-based approach-

Facility: ______________________________

System: ______________________________

By: ____________________ Date: ____________

Field observations, discussions with operators

Look for:	YES	NO
Significantly throttled valves in primary flow path(s)		
Normally open pump bypass line used for flow control or pump minimum flow protection		
Multiple parallel pumps where the number of operating pumps is seldom changed		
Batch or cyclical start/stop system with frequent pump cycling		
Significant cavitation noise at the pump or in the system		

Looking at the forest, not the trees

Consider:	YES	NO
Should the system flow or head requirements change over time (time can include from hours to months)? (If the answer is yes, but either a variable speed drive or multiple parallel pumps are available and used, check no).		
Have the system requirements changed over the course of time (normally years), but the system design has remained fixed?		

Complete the following only for systems with variable speed drives

Consider:	YES	NO
Is the system dominated by static head, with only a single pump normally in operation?		
Does the system still have high pressure drop valves installed (typically, where a drive has been retrofitted to the pump)?		
Is the speed control device an older drive, such as an eddy current device or a wound rotor motor normally operated at reduced speed?		

Notes:

Energy use primary screening

Facility: ____

System	Device Name/ID	Rated HP	Annual operating hours	1000's HP-hrs	Fluid system?	Review further?	Notes

By: ______________________________ Date: ______________________

Pump system screening imbalance sheet

Facility: ____

System	Required system gpm	Required system head (ft)	Measured pump gpm	Measured pump head (ft)	Imbalance* (percent)	Review further?	Notes

By: ____________________________

*Imbalance % = {[(Measured gpm * Measured ft)/(Required gpm * Required ft)] - 1} * 100

Date: ____________________________